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COMBINATION OF AN ELECTROLYTIC PRETREATMENT UNIT WITH SECONDARY WATER RECLAMATION PROCESSES

SMG

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FOREWORD

The work described in this report was performed under NASA-JSC Contract No. NAS1-11781, originally awarded by NASA-LaRC, by the Biotechnology and Space Sciences Department, McDonnell Douglas Astronautics Company (MDAC). The design and fabrication of the air evaporation unit and preparation of the test facility were funded by MDAC Independent Research and Development Programs.

The authors wish to acknowledge the major contributions made to this program by the following MDAC personnel:

- E. P. Honorof - Chemical Analysis
- D. L. Magargee - Configuration Evaluation
- R. E. Shook - Mechanical Design
- M. Sofios - Microbial Analysis
- R. L. Vaughan - Electrical Design and Test Monitoring
- W. Wong - Engineering/Fabrication Coordination

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Section 1
SUMMARY

The principal objective of this study was to design, fabricate, and verify the operation of an electrolytic pretreatment unit (EPU) when operated in conjunction with an air evaporation unit (AEU) for the recovery of potable water from human urine. The EPU portion of the program was conducted under NASA/JSC Contract No. NAS1-11781, and the AEU was supported by the McDonnell Douglas Astronautics Company independent research and development (IRAD) program.

The EPU and the AEU are shown in Figures 1-1 and 1-2. Both units are automated, six-man, flight-concept prototype units, and collectively are identified as the Electrovap system. The Electrovap system utilizes the EPU to pretreat human urine electrolytically for partial organics removal, followed by air evaporation and distillation in the AEU for the removal of the remaining organics and the removal of inorganic salts and convert the pretreated urine into potable water. The system is self-sterilizing and was developed for space missions of medium to long-term duration. The Electrovap system incorporates fail-safe control features and is designed for unattended operation.

After fabrication, assembly, and checkout, the EPU and AEU were integrated and operated in conjunction with each other for five days. The operation of both units was successful, with only minor malfunctions. This test, during which 108.5 lb of urine and 27.1 lb of flush water were processed, verified the feasibility of the Electrovap concept for water reclamation. Pretreatment by the EPU reduced the average total organic carbon concentration (TOC) to 778 parts per million (ppm) and the AEU produced water with an average TOC of 10.42 ppm, an average conductivity of 12.9 μmhos/cm, and an average total dissolved solids (TDS) content of <1 ppm. Although high ammonia levels in the product water may be encountered when processing chemically pretreated

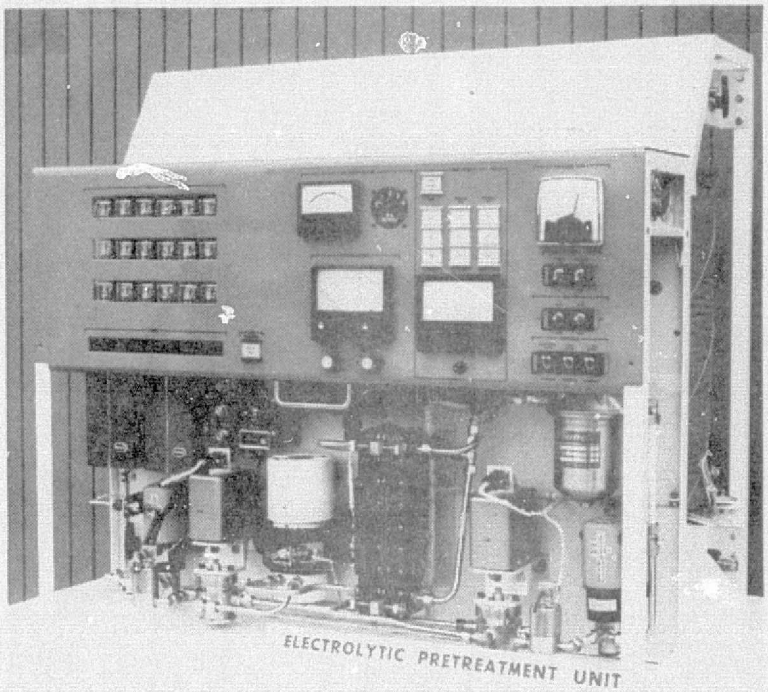

Figure 1-1. Electrolytic Pretreatment Unit

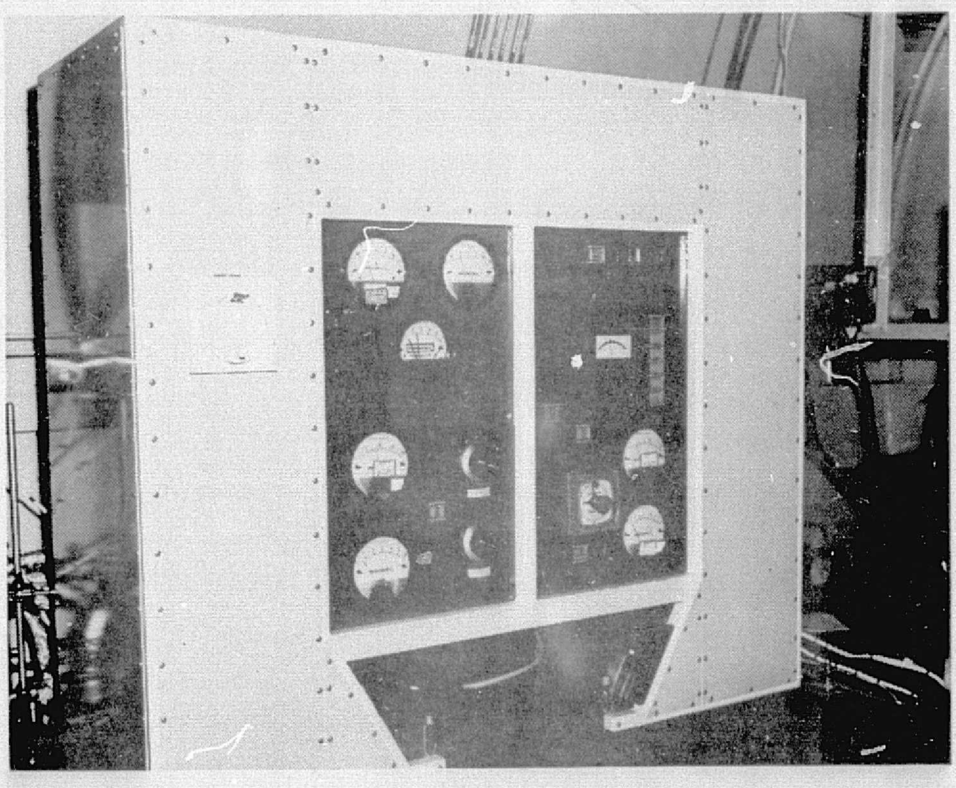

Figure 1-2. Air Evaporation Unit

urine at temperatures above the urea breakdown temperature, operation of the AEU with an inlet wick temperature of 200°F did not produce an unacceptable amount of ammonia in the product water.

Product water of the Electrovap system met all the standards of the National Academy of Sciences-National Research Council (NAS-NRC) for potable water with the exception of the pH standard. The average pH of the water produced in the five-day test was 6.4, while the NAS-NRC pH standard is 7 to 8. (The pH of the product water could be adjusted with a simple ion exchange post-treatment module.) A trace of foaming was detected in the product water during the first four days. However, on the fifth day, all traces of foaming had disappeared. It is suspected that this foaming was produced by materials introduced into the AEU during the manufacture of one or more commercial components installed in the unit.

During this study, plans were also prepared for extended testing of the Electrovap system to produce data applicable to the combination of electrolytic pretreatment with most final water purification systems. Plans were also prepared for a program to define the design requirements to combine the EPU with a reverse osmosis water recovery unit.

Section 2
INTRODUCTION

Future long-duration manned space missions will need potable water to be reclaimed from human wastes to conserve weight and volume. The water recovered from these wastes must meet exacting standards for chemical and microbial purity, and the processing systems used must perform with high reliability and efficiency in a zero-gravity environment. The systems used must be of minimum size and weight, and use a minimum of expendable materials.

In urine reclamation systems, the primary source of possible toxic contaminants is the urine itself. Decomposition of the urea content of the urine raises the ammonia concentration in the urine from a nominal 550 ppm to 14,000 ppm, rendering it toxic. To avoid urea decomposition and the accompanying production of ammonia and other unacceptable organic contaminants in the product water, some form of urine pretreatment is required. Both chemical and electrolytic pretreatment methods have been developed for this purpose (References 1 and 2).

Chemical pretreatment is obtained by adding expendable oxidizing agents, such as chromium trioxide, that form stable soluble ammonium salts from the urea. Electrolytic pretreatment is obtained by the passage of a direct current through a cell containing platinum electrodes to oxidize and remove organic materials, such as urea, from urine prior to final purification. The electrochemical reactions (Reference 2) convert the organic contaminants into useful recoverable gases such as CO_2, H_2, O_2, and N_2 and eliminate microbial contaminants through the production of excess chlorine from urine salts. The resulting semi-purified urine contains 2 to 2.5 percent of primarily inorganic salts which must be removed by a final treatment system to obtain potable water.

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This report describes the design and fabrication of a flight concept prototype electrolytic pretreatment unit (EPU) and of a contractor-furnished air evaporation unit (AEU). The integrated EPU and AEU potable water recovery system is referred to as the Electrovap and is capable of processing the urine and flush water of a six-man crew.

The report also presents results of a five-day performance verification test of the Electrovap system and plans are included in the Appendix for the extended testing of the Electrovap to produce data applicable to the combination of electrolytic pretreatment with most final potable water recovery systems. Plans are also presented in the Appendix for a program to define the design requirements for combining the electrolytic pretreatment unit with a reverse osmosis final processing unit.

Section 3
PROGRAM OBJECTIVES

The objectives of this program were:

A. To design and fabricate an electrolytic pretreatment system that can be used to verify, by demonstration tests, the benefits projected for combining electrolytic pretreatment with several different final processing subsystems for water recovery.

B. To integrate the completed electrolytic pretreatment unit with a contractor-furnished air evaporation unit and to subject the overall configuration to a five-day operational verification test.

C. To devise a plan for extended operation of the combined electrolytic pretreatment and air evaporation units to obtain data common to the use of electrolytic pretreatment with all distillation systems.

D. To prepare plans to define the design requirements for combining electrolytic pretreatment with a reverse osmosis water reclamation unit.

Section 4
PRELIMINARY DESIGN

Preliminary designs of the electrolytic pretreatment unit (EPU) and the air evaporation unit (AEU) were prepared to determine component sizes and flow rates and to show the relative locations of components, plumbing, and control and monitoring panels. The results of the preliminary design studies are presented in this section.

4.1 ELECTROLYTIC PRETREATMENT UNIT PRELIMINARY DESIGN

A preliminary electrolytic pretreatment unit design was prepared indicating the function, arrangement, and operation of all dynamic components. The preliminary design was based on portions of the technology developed in the construction of the electrochemical water recovery system under a previous NASA contract, NAS1-8954 (Reference 2). The concepts developed in the previous program were utilized in the EPU preliminary design, and additional control system flexibility was incorporated to allow the unit to be readily integrated with any of several final processing methods.

4.1.1 Design Requirements

The unit was designed to process urine and flush water for a crew of six. A design process capacity of 25.86 lb of urine and flush water per day was used, based on a urine output of 3.45 lb/person-day and a flush water usage of 0.86 lb/person-day. A design process rate of 3.22 lb/hr was selected to allow pretreatment of each day's urine and flush water in 8 hr of processing time. The minimum portion of candidate space station orbits in sunlight is approximately 14 hr, allowing ample time for processing in sunlight only (corresponding to times of increased electrical power for missions using solar cells) with sufficient reserve for makeup processing in the event of a unit malfunction.

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Comparative data on actual and design point urination volumes and calculated processing times for the EPU and the AEU are given in Table 4-1. Processing times in the table are based on a urine organic content of about 24,000 ppm The EPU process time is keyed to the amount of organic material that must be removed, not the amount of liquid to be processed. The air evaporator process time is, however, directly related to the amount of liquid to be processed, and its worst case is the Space Station Prototype (SSP) design point for a male-female urinal, 13.9 hr.

Table 4-1

COMPARATIVE URINATION AND FLUSH WATER VOLUMES AND CALCULATED PROCESSING TIMES

Source	Output Rate (lb/person-day)	6-Person Output Rate (lb/day)	6-Person Flush Water Usage (lb/day)	6-Person Total For Day (lb/day)	EPU Hours To Process (hr)	Air Evap Hours To Process (hr)
EPU design point	3.45	20.70	5.16	25.86	8.0	8.0
SSP design point (male urinal)	3.44	20.65	12.00	32.65	8.0	10.0
SSP design point (male-female urinal)	3.44	20.65	24.00	44.65	8.0	13.9
90-day test maximum	5.00	30.00	5.16*	35.16	11.6	10.9
90-day test average	3.31	19.86	5.16*	25.02	7.7	7.8
90-day test minimum	1.82	10.92	5.16*	16.08	4.2	5.0

*5.16 selected for comparative purposes. Actual flush water used in automatic mode of urinal flushing was 0.54 lb/person-day (for 6 persons this would be 3.24 lb/day).

Table 4-2 lists the constraints and guidelines followed in the preliminary design of the EPU. The control logic, transfer cycles, and process circulation cycle methods employed in the design were selected to be compatible with a zero- to 1-g environment. To avoid high costs, nonpressurized 1-g tanks are used with liquid level float-type quantity sensors to provide volume control and readout. Also, to avoid employing a zero-g liquid gas separator, the electrolytic batch tank serves as a separator, and is continually vented. The switch closure quantity signals used as inputs to the control logic with this type of system are comparable to quantity signals produced by zero-g position indicating bellows systems, and thus the logic functions are identical to a zero-g design.

4.1.2 Flow Diagram

The mechanical schematic prepared in the preliminary design is shown in Figure 4-1. No changes were made in this basic configuration in the latter phases of the program.

The incoming urine and flush water pass through a liquid level controlled solenoid valve (SV5), which prevents overfill of the urine storage tank. When a batch is to be processed, the inlet valve (SV2) is moved to the transfer position and the urine transfer pump (P1) is activated to fill the electrolysate tank. SV2 is then positioned to allow circulation through the cell, and the circulation pump (P2) is activated. On completion of batch processing, signaled by a timer and an oxygen sensor, the outlet valve (SV1) is positioned to transfer the liquid to the pretreated urine storage tank and the pretreated urine transfer pump (P3) is activated.

4.1.3 Materials Evaluation

To evaluate candidate materials for use in the Electrovap design, a glassware materials test setup was fabricated. A schematic of the test rig is shown in Figure 4-2, and a list of materials evaluated is presented in Table 4-3. The test loop used a nutating disc pump to circulate 2-liter batches of urine and flush water through an electrolysis cell. The circulating pump and electrolysis cell designs were identical to those proposed for use in the EPU. The temperature of the circulating

Table 4-2

DESIGN CONSTRAINTS AND GUIDELINES

Mission Model	
Mission duration	2 years
Resupply capability	180 days
Gravity mode	see text
Mission objective	Space station/space base
Vehicle Model	
Compartment size	Diameter: 156 in. Height: 82 in.
Crew Model	
Number of crewmen	6
Height of man	6 ft
Weight of man	160 to 190 lb
Metabolic activity Average for 24 hours	150 percent (zero g) Basal metabolism rate
Atmosphere Model	
Cabin total pressure	7.0 to 14.7 psia
Gas composition	3.5 psia oxygen diluent nitrogen
Carbon dioxide Partial pressure	0 to 3.0 mm Hg
Temperature (dry bulb)	65° to 75°F adjustable
Dew point	46° to 57°F for any dry bulb temperature
Waste Water Model (Maximums)	
	lb/man-day / lb/day
Urine	3.45 / 20.70
Flush	0.86 / 5.16

electrolysate was limited to approximately 150°F with the use of a single-pass shell and tube heat exchanger, using city water for coolant.

Nine batches were processed in the materials test rig, as indicated in Table 4-3. Materials were placed in the test chamber so that they were

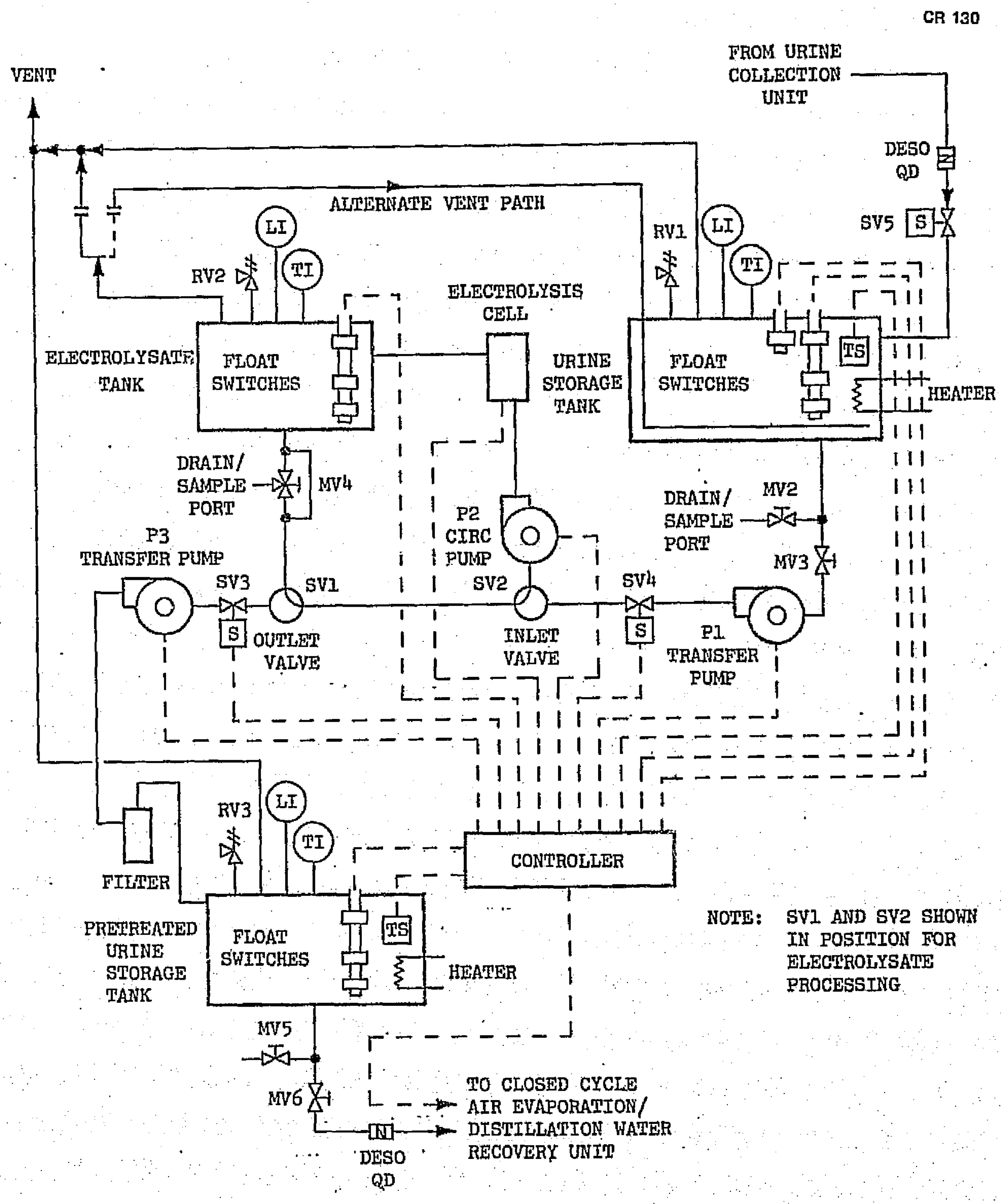

Figure 4-1. Preliminary Design Schematic of the Electrolytic Pretreatment Unit

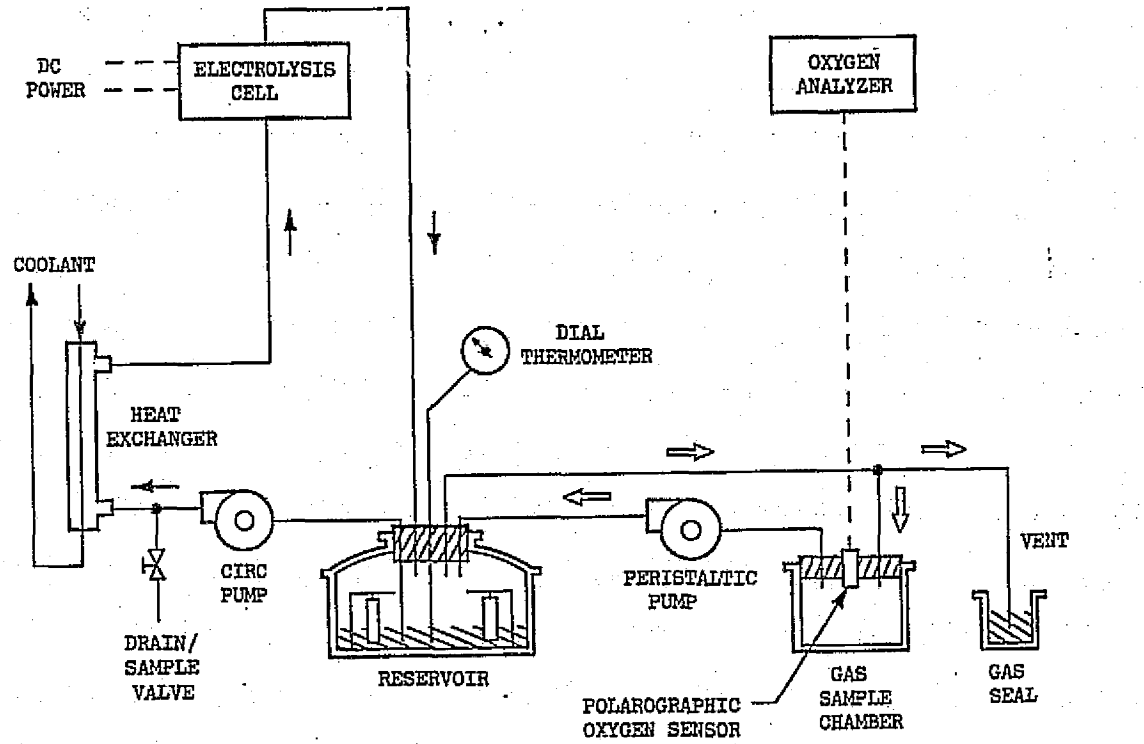

Figure 4-2. Test Setup for Materials Evaluation

half in the urine and flush water being electrolyzed (electrolysate) and half in the vapor above the electrolysate. After the last batch was processed, the materials under test were left in the pretreated urine solution for a period of 40 weeks. The materials were then removed from the solution and the photograph in Figure 4-3 was taken.

All uncoated metals exhibited evidence of corrosion in the vapor portion of the test chamber. Stainless steels tested exhibited very little corrosion when in liquid only. All plastics tested except for urethane foam appeared relatively unaffected by the environment. The uncoated urethane foam lost all of its strength and disintegrated after being in the test chamber during the processing of five batches. The urethane foam coated with polyvinyl chloride (PVC) lost much of its compressive strength but maintained its form. Examination of the PVC-coated foam after the 40-week soak in the pretreated urine revealed no additional loss in strength. Because the available performance data from previous programs using similar wick packages were obtained using urethane foam spacers in the wick air-flow passages, it was decided to use the PVC-coated foam in the wick packages

Table 4-3
MATERIALS EVALUATED IN TEST SETUP

Material	5 Sept 72	6 Sept 72	7 Sept 72	8 Sept 72	11 Sept 72 (Batch 1)	11 Sept 72 (Batch 2)	14 Sept 72	15 Sept 72	25 Sept 72
1/4-in.-OD polyethylene tube	X*		X	X	X	X	X	X	X
1/4-in.-OD polypropylene tube	X		X	X	X	X	X	X	X
3/8-in.-OD polypropylene tube	X		X	X	X	X	X	X	X
3/16-in.-OD vinyl plastic tube	X		X	X	X	X	X	X	X
1/8-in.-thick polycarbonate sheet	X		X	X	X	X	X	X	X
1/4-in.-thick acrylic sheet	X		X	X	X	X	X	X	X
AN804D aluminum tee		X	X	X	X	X	X	X	X
CRES Type 316 wool		X	(Badly rusted after one batch)						
CRES Type 316 tee (in vapor only)		X	(Rust visible after one batch)						
Urethane foam		X	X	X	X	X	(Disintegrated)		
PVC-coated urethane foam		X	X	X	X	X	X	X	X
Polyethylene netting		X	X	X	X	X	X	X	X
Rayon viscose felt			X	X	X	X	X	X	X
1/32-in.-OD CRES Type 308 ELC rod			X	X	X	X	X	X	X
1/4-in.-OD 6061-T6 Al tube			X	X	X	X	X	X	X
Coaxial connector - gold anodized			X	X	X	X	X	X	X
1/16-in.-OD polypropylene rod									X
1/14-in.-OD CRES Type 304 tube			X	X	X	X	X	X	X
AN CRES Type 304 B-nut			X	X	X	X	X	X	X
AN CRES Type 316 B-nut			X	X	X	X	X	X	X
AN CRES Type 316 Union			X	X	X	X	X	X	X
5/8-in.-OD CRES Type 347 tube									X
1/16-in.-OD CRES Type 347 rod		X	X	X	X	X	X	X	X
1/8 -in.-OD Teflon tube		X	X	X	X	X	X	X	X
Type 106 RTV adhesive									X
Type 109 RTV adhesive									X
Type 118 RTV adhesive									X

*X's donote dates on which materials were tested.

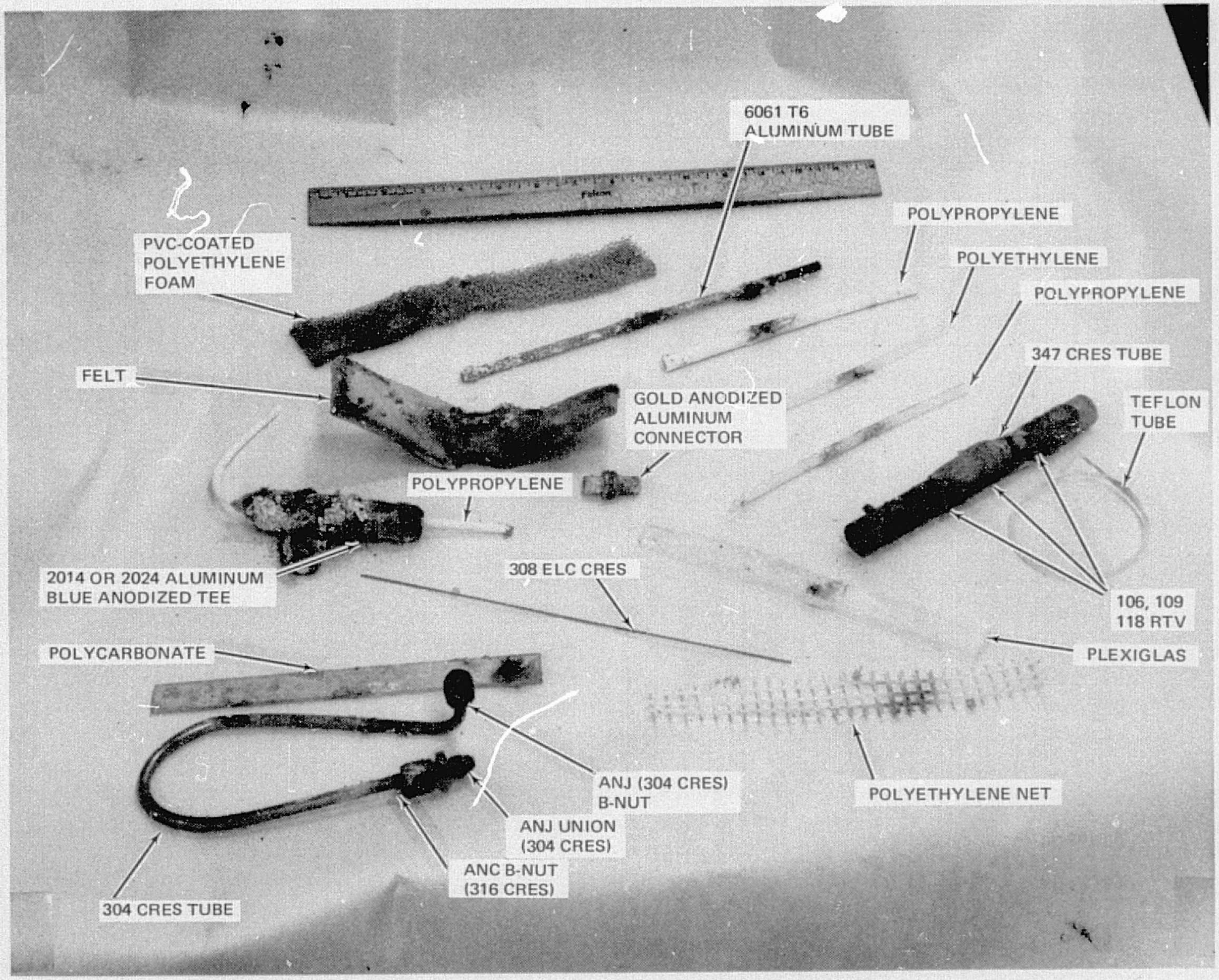

Figure 4-3. Materials Evaluated in Test Setup

for this program even through this material was not completely resistant to the effects of pretreated urine.

Anodized aluminum withstood the test chamber environment relatively well. However, scratches or chips in the anodizing quickly precipitated blisters and corrosion under the surrounding coating, and led to a spreading of corroded areas.

4.1.4 Polarographic Oxygen Sensor

The concentration of the oxygen gas above the electrolysate was previously found to be a reliable indicator of the completion of the conversion of organics to inorganics in the electrolytic loop. Accordingly, a polarographic oxygen sensor with appropriate readout was installed in the materials test loop to evaluate sensing oxygen content of the by-product gas as a method of process control.

A typical oxygen concentration curve obtained with the polarographic sensor shows that the oxygen level dropped rapidly at the start of processing and remained at a level of less than 5 percent until near the end of the processing cycle. This is indicated in Figure 4-4. Batch sizes were found to have little effect on the basic curve shape, but influenced the time scale of the curve.

Repeatable performance was obtained from the oxygen analyzer for the several batches processed, and it was believed that control of the end point of the pretreatment process by the oxygen content of the by-product gas would enable pretreatment of each batch processed to a similar total organic carbon level. The polarographic oxygen sensor control is used in conjunction with a timer in the EPU design to ensure that each batch is processed for a minimum time and that the oxygen content in the by-product gas drops to a preset low level and then rises to a preset upper limit.

4.1.5 Control Methods

In addition to the polarographic oxygen sensor and timer control of the pretreatment end point, logic and control methods were evaluated for all modes of unit operation. A preliminary operating sequence was developed as

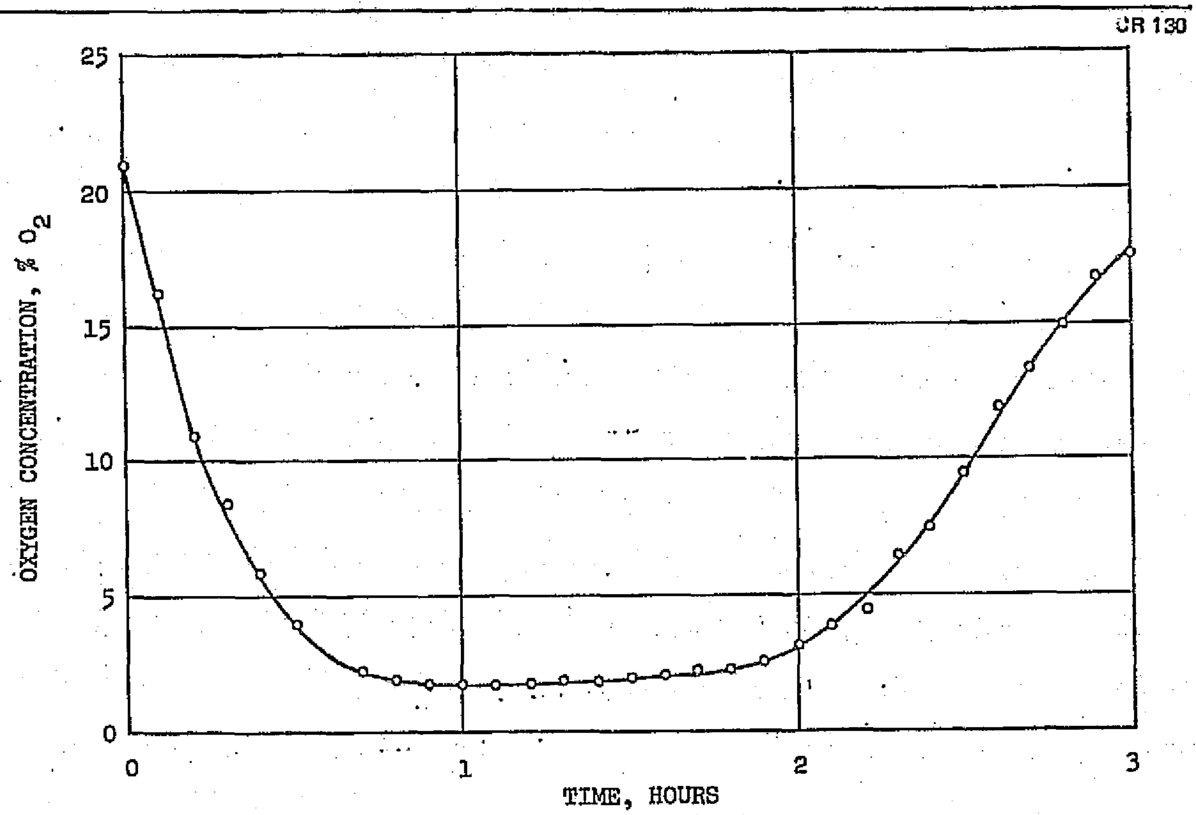

Figure 4-4. Polarographic Oxygen Sensor Reading — 2-Liter Batch

shown in Figure 4-5, and methods of implementing the desired control functions were evaluated.

Manual overrides were evaluated for all control functions, and four key functions were identified on which manual override or mode selection switches were necessary. These are: (1) oxygen sensor override switch, (2) timer override switch, (3) tank heater operation mode switch, and (4) electrolysate transfer control switch. Other than these override functions, all unit operations are carried out only under automatic control.

4.1.6 Configuration Evaluation

Careful attention was given to the EPU configuration and layout in the preliminary design phase. Design analysis considered not only man's interaction with the equipment in laboratory tests, but also human engineering design for eventual utilization in space. The design study considered such human engineering factors as overall operability and maintainability, accessibility, standardization of fasteners and tools, selection and layout of controls and displays, and packaging of components for ease of maintenance.

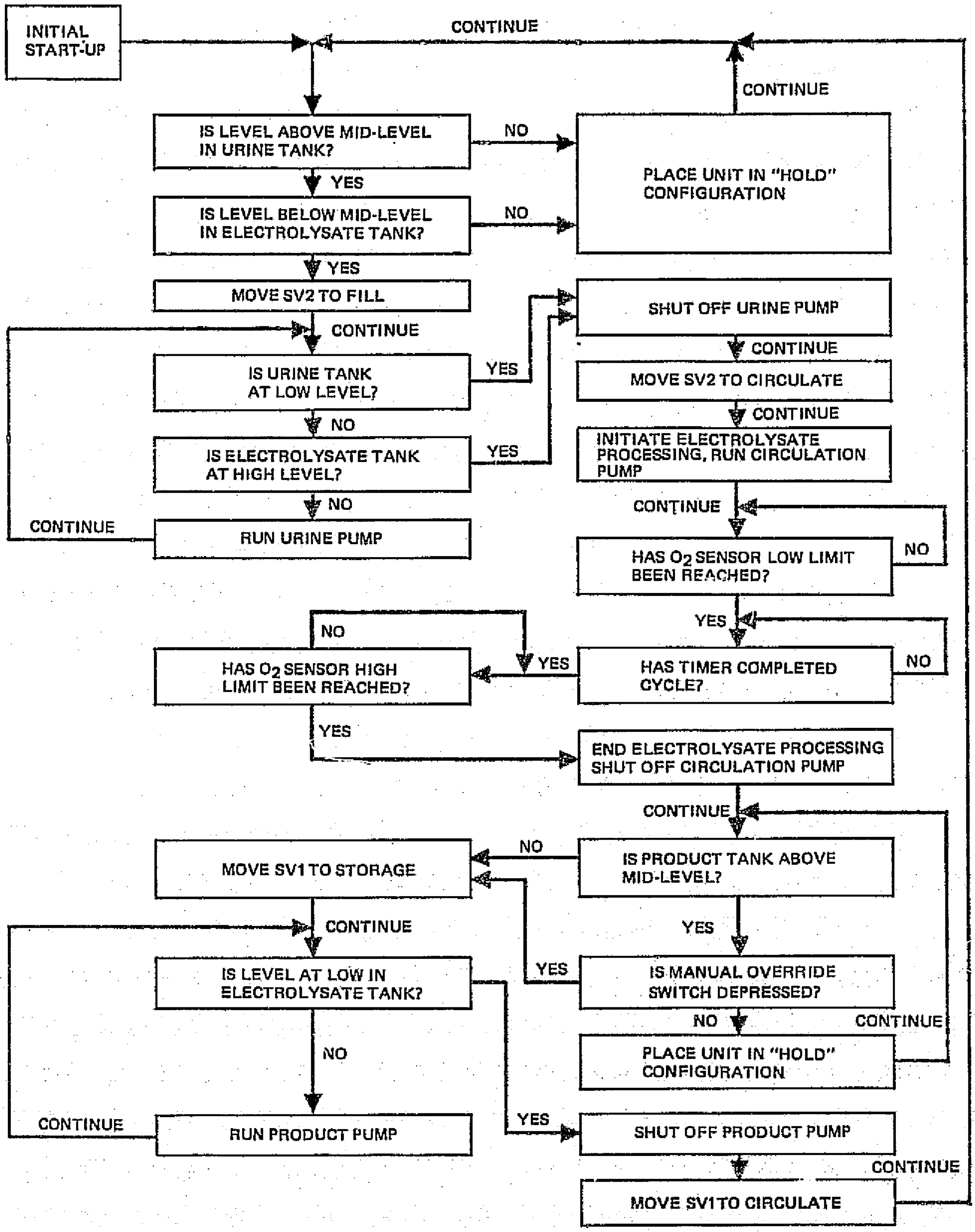

Figure 4-5. Logic Flow Diagram of Preliminary Design

Although the scope of the program did not permit extensive use of custom-designed and manufactured parts, all the human engineering considerations were implemented in the design of the unit to the fullest extent possible within schedule and budgetary constraints.

Early in the preliminary design work, the following ground rules for the configuration were formulated:

A. Based on the frequency of access required, it was decided to provide front access for major components in the EPU (pumps, plug valves, electrolysis cell, filters, and controllers) as well as for operating and monitoring controls and displays. Rear access was to be provided for the urine storage tanks.

B. To minimize the number of tools required, the concept of standardized fasteners was adopted for mounting replaceable components. Rapid access was to be provided to the rear of the control panel.

C. Ease of maintenance was to be an important consideration in the arrangement and packaging of all components, and electrical components were to be provided with electrical connectors to allow ready replacement or removal for servicing at a remote work station.

D. Controls and displays were to be grouped into functional arrangements and where appropriate, guards specified to prevent inadvertent control actuation.

Experience accumulated in the development of similar life support units was used for preparing preliminary configuration layout sketches. Next, full-scale soft mockups (made from a cardboard-styrene foam-cardboard sandwich material) of individual components were constructed. Taking advantage of the flexibility of the soft mockup technique, various arrangements of the components were assembled and evaluated. Mockups of the individual components were refined, rearranged, and evaluated by engineers with experience on previous versions of the electrolytic pretreatment unit.

Figures 4-6 through 4-8 show some of the configurations of the individual mockup components which were evaluated before arriving at the final configuration shown in Figure 4-9.

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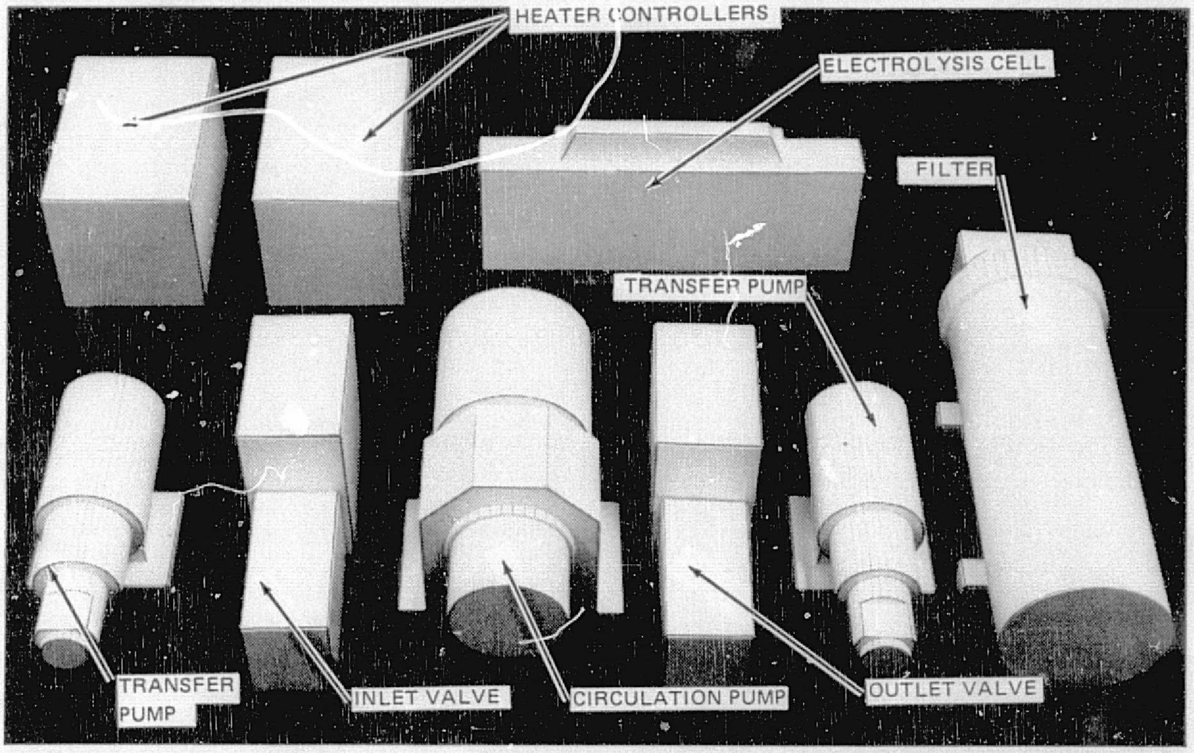

Figure 4-6. Dynamic Component Arrangement of Electrolytic Pretreatment Unit – Horizontal Electrolytic Cell

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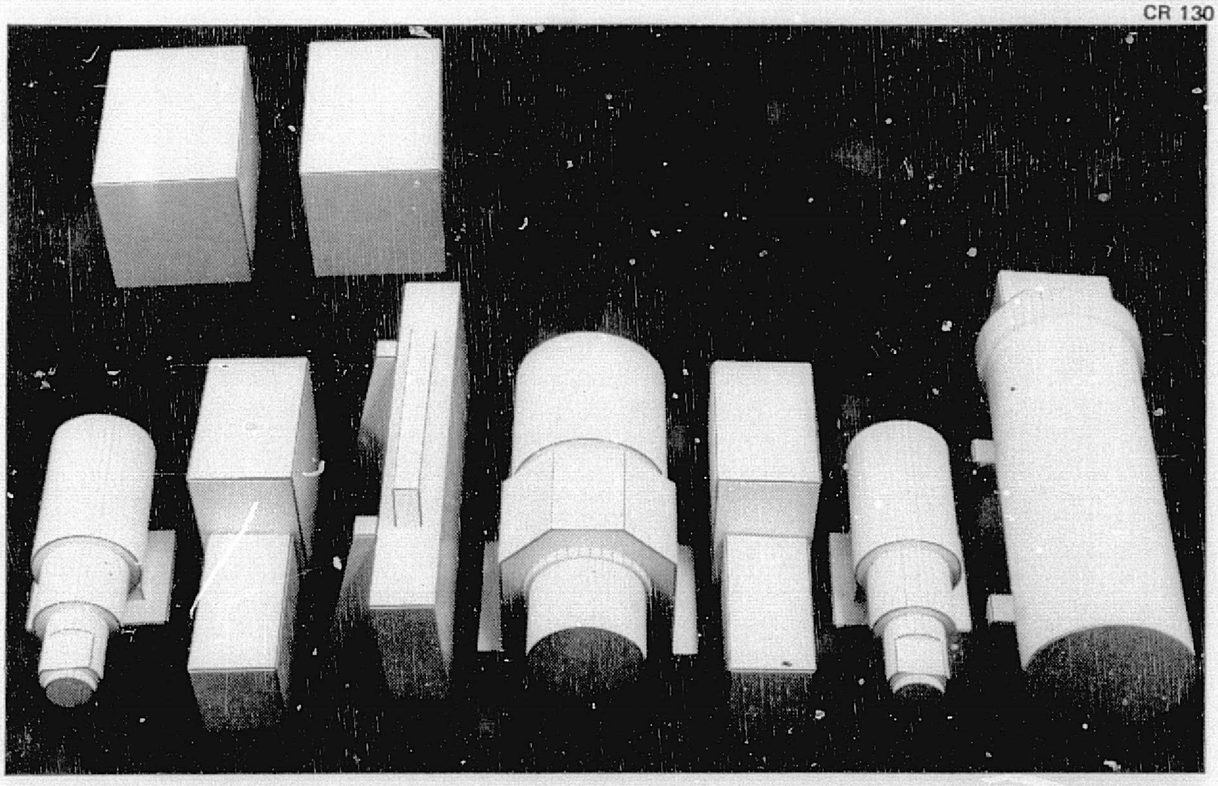

Figure 4-7. Dynamic Component Arrangement of Electrolytic Pretreatment Unit – Vertical Electrolytic Cell

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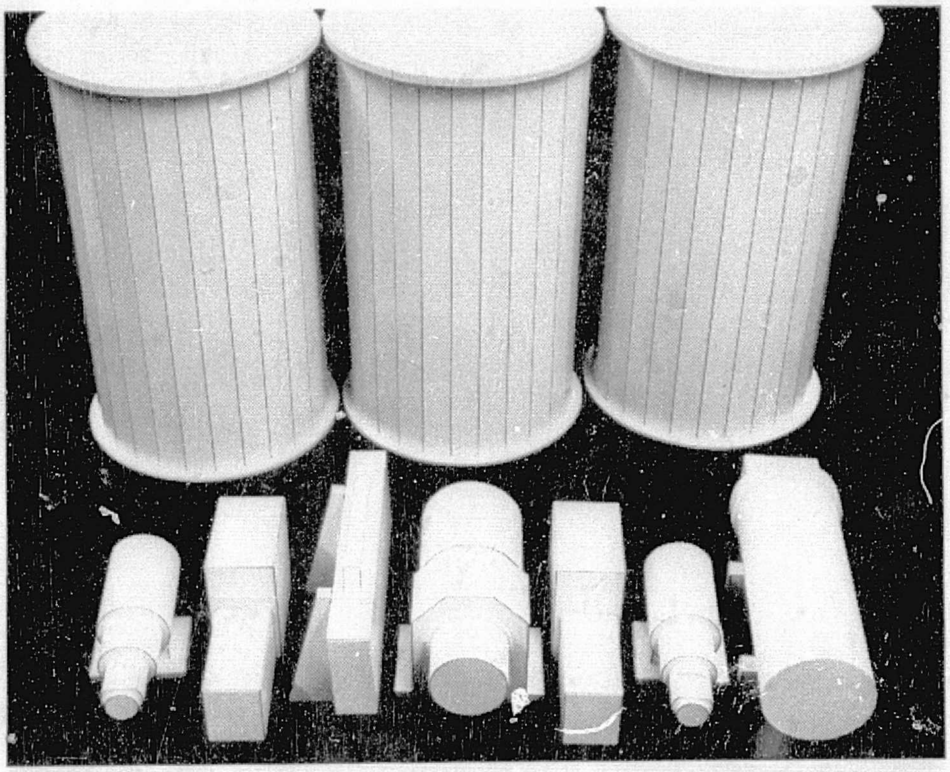

Figure 4-8. Trial Component Arrangement of Electrolytic Pretreatment Unit – Vertical Tankage with Dynamic Components Horizontal

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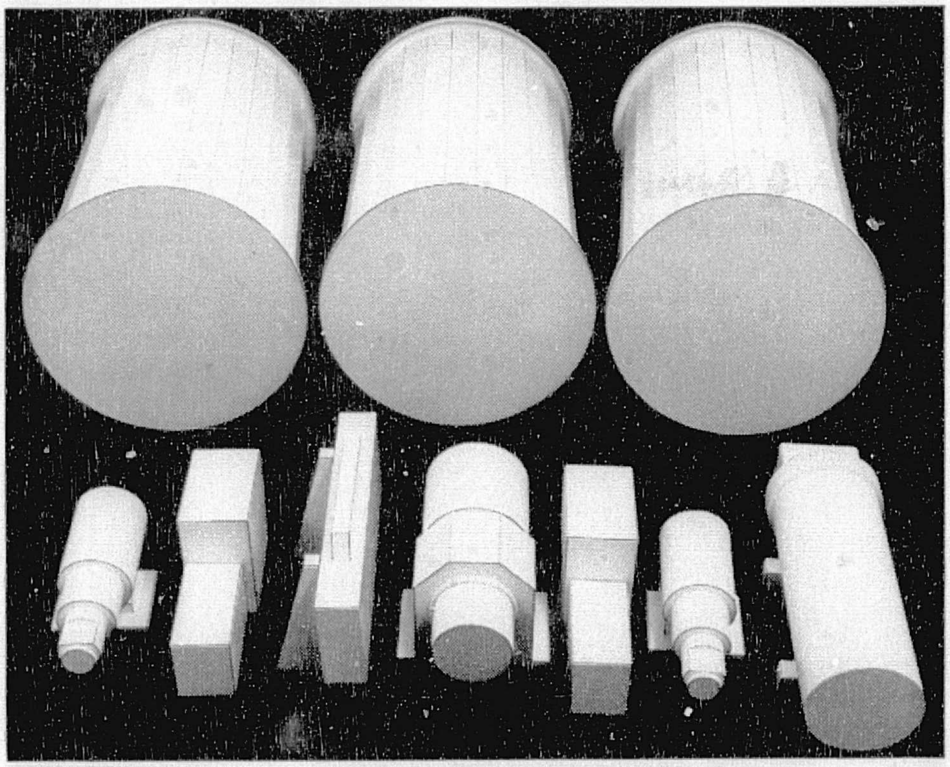

Figure 4-9. Final Component Arrangement of Electrolytic Pretreatment Unit

After the basic three-dimensional component arrangement was determined, soft mockups of the frame, logic package, and control panel were fabricated, and all individual component mockups were assembled into a mockup of the completed EPU.

Figure 4-10 is a photograph of the front view of the completed mockup. The rear view of the mockup is shown in Figure 4-11.

The soft mockup technique proved to be an invaluable tool in the preliminary EPU design. With this method, a great variety of configurations could be evaluated rapidly. Clearances and maintainability aspects were readily apparent from inspection of the three-dimensional layouts, and control panel arrangement and nomenclature were evaluated in full-size, three-dimensional form.

4.2 AIR EVAPORATION UNIT PRELIMINARY DESIGN

Table 4-4 presents the major activity areas required for the preliminary design of the closed-cycle air evaporation unit. This unit was designed utilizing experience and test data from similar units developed for the NASA 60- and 90-day manned test programs conducted by MDAC (References 3 and 4). Since this unit processes electrolytically pretreated rather than chemically pretreated urine that was used for the 60- and 90-day test units, the materials of construction of the new unit were upgraded to withstand temperatures to 220°F and the corrosive vapors expected from electrolytically pretreated urine. Also, the wick package was redesigned using materials that could withstand the concentrated brine and dried residues resulting from dehydrated, electrolytically pretreated urine.

4.2.1 Design Requirements

The AEU design urine feed rate of 3.22 lb/hr was based on the EPU design requirements discussed previously. For this preliminary design, the following performance envelope was selected for analysis:

Maximum wick inlet temperature = 220°F
Minimum wick inlet temperature = 160°F
Maximum wick inlet dew point = 100°F
Minimum wick inlet dew point = 60°F

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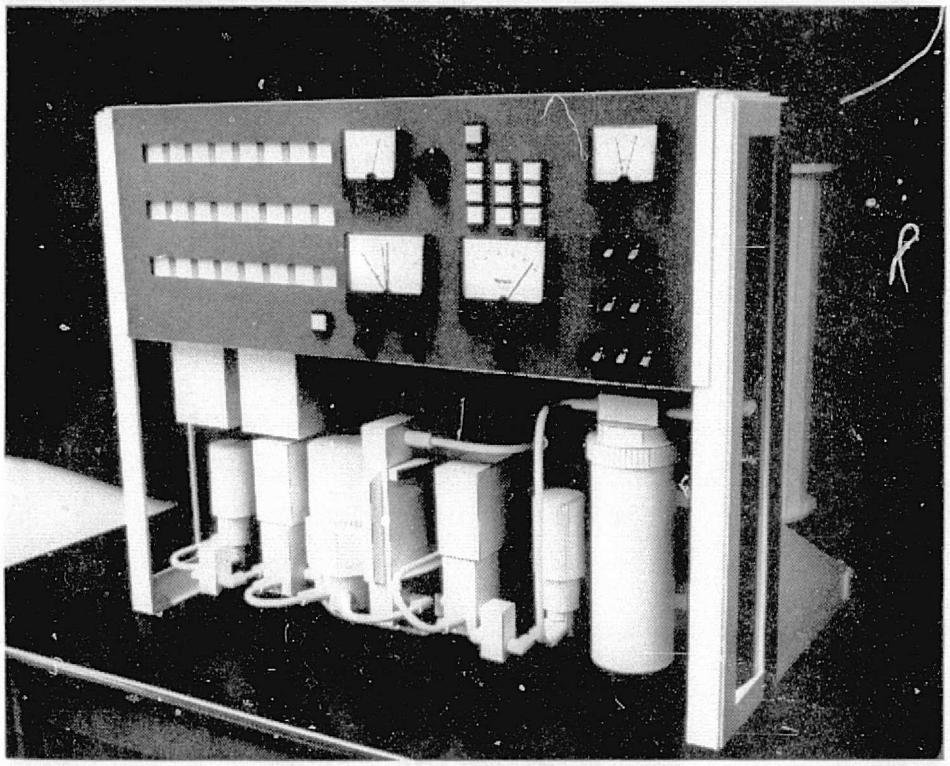

Figure 4-10. Front View of Completed Mockup of Electrolytic Pretreatment Unit

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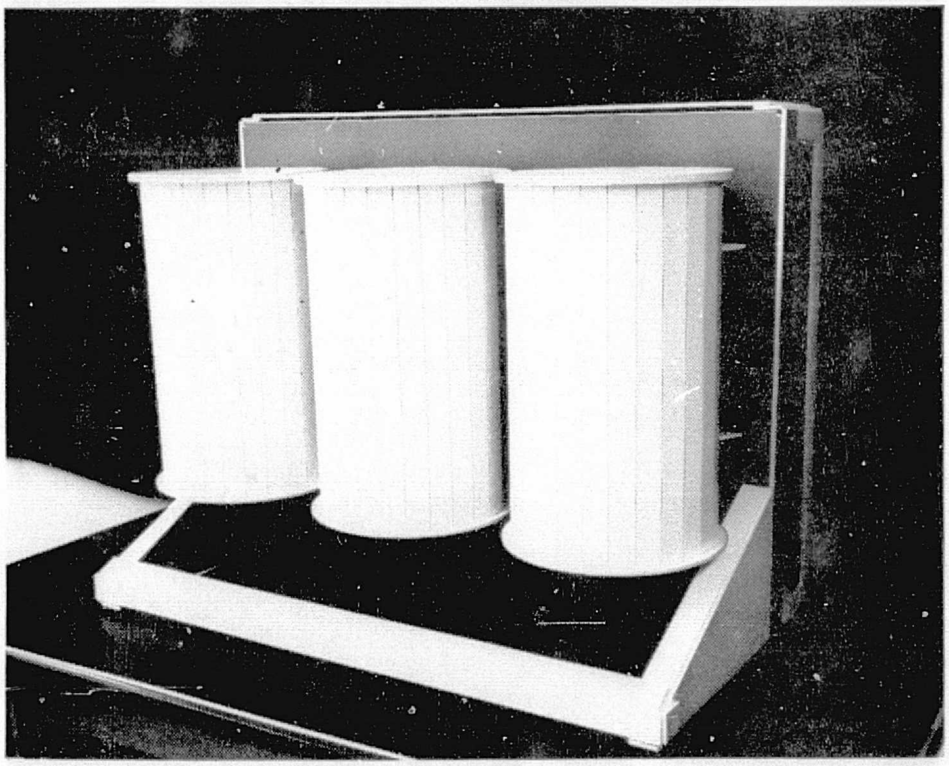


Figure 4-11. Rear View of Completed Mockup of Electrolytic Pretreatment Unit

Table 4-4

AIR EVAPORATION UNIT PRELIMINARY DESIGN

Design Phase	Activity
Design Analysis	•Thermal and mass transfer •Correlation with test data •Design requirements •Off-design performance evaluation
Material and Component Selection	•Corrosion resistance •High temperature resistance •Component performance evaluation
Controls and Instrumentation	•Urine feed control and measurement •Condensate rate measurement •Fault isolation •Performance evaluation instrumentation
System Integration	•Maintainability •FMECA •Off-design operation flexibility

AEU design analysis was made with these operational limits to provide sufficient information to evaluate system performance at off-design points.

4.2.2 Flow Diagram

Figure 4-12 illustrates the basic air evaporation/distillation cycle. Pretreated urine is metered and fed to the wick, where the water is evaporated into the heated airstream. The humid air then passes through the carbon and particulate filter and through the condenser, where the water is removed. The blower then recycles the dehumidified air back through the air heater, where the temperature is increased to the design set point, and into the wick.

4.2.3 Evaporator Ideal Performance

The ideal air evaporator performance, shown in Figure 4-13, was calculated by an analysis similar to that described in Reference 5. Figure 4-13 is a performance map of an ideal wick evaporator which assumes that all water is evaporated and the air leaves the wick at the adiabatic saturation temperature. The map assumes that the evaporator heat and mass transfer

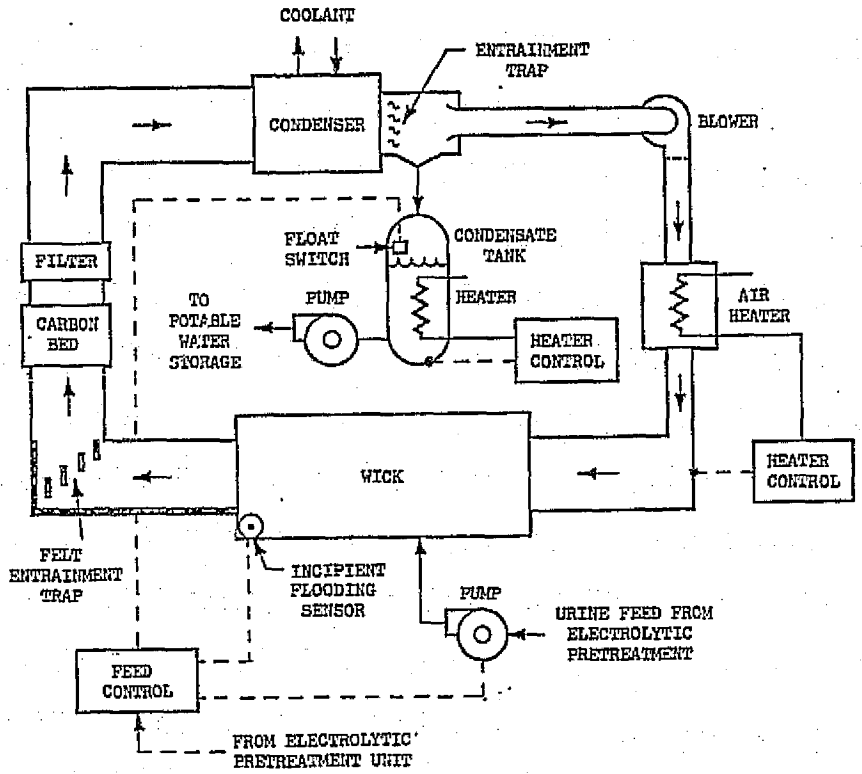


Figure 4-12. Preliminary Design Flow Diagram of Air Evaporation Unit

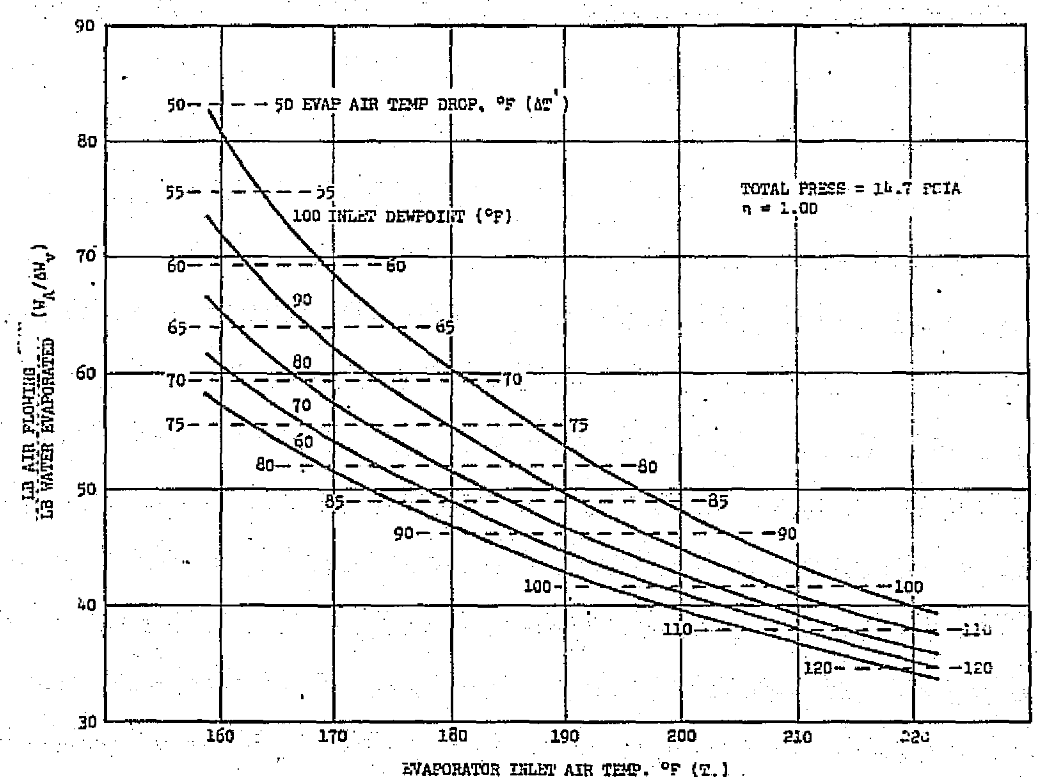


Figure 4-13. Ideal Performance of Air Evaporator Wick

parameters are sufficient to achieve an effectiveness (η) equal to 1.0. The actual evaporator would not achieve this performance due to the boiling point rise of urine, or to the lack of sufficient area in the evaporator for heat and mass transfer, or both. However, as will be indicated, this curve can be used with an actual evaporator performance map to evaluate the predicted AEU performance.

4.2.4 Evaporator Actual Performance

In order to calculate an actual evaporator performance map, the geometry of the wick evaporator must be known. For this preliminary analysis, the wick design for the 90-day test (Reference 4) was assumed, since operating experience and test data are available for this design. A predicted air evaporator performance map, shown in Figure 4-14, was calculated by an analysis similar to that described in Reference 6.

A design point was established as follows:

Urine feed rate (ΔW_v) = 3.22 lb/hr
Inlet air temperature = 200°F
Inlet air dew point = 80°F

From this design point, an effectiveness (η) of 0.722 was determined from Figure 4-14. The actual air flow and wick temperature drop were calculated from the ideal performance curve (Figure 4-13) by the following relationships:

$$\text{Actual air flow (lb/hr} = (W_a/\Delta W_v)' \times 3.22/0.722$$
$$= (43) \times 3.22/0.722 = 191 \text{ lb/hr}$$

$$\text{Actual temperature drop} = 0.722 \times \Delta T' = 0.722 \times 98 \cong 72°F$$

The design air flow was calculated to be 191 lb/hr or 53 cfm. For comparison, the air flow required to increase the feed rate to 5.0 lb/hr was calculated to be 74 cfm with the maximum inlet air temperature of 220°F. Using this method, the performance at other inlet dew points and inlet temperatures was calculated at 53 and 74 cfm. Actual test data from the 60- and 90-day tests have been checked with this analysis and very good correlation was obtained.

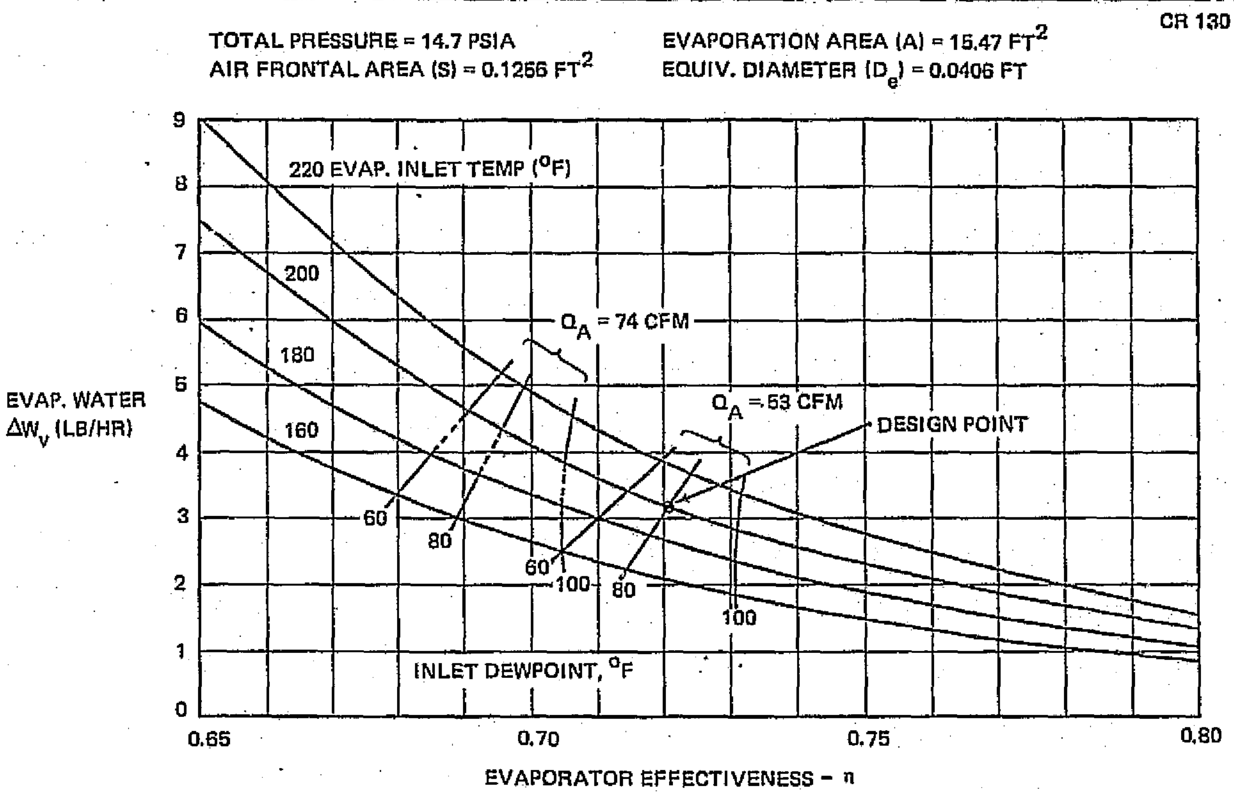


Figure 4-14. Predicted Performance of Air Evaporator Wick

4.2.5 Controls and Fault Isolation

The basic control and fault isolation requirements for the AEU which were studied during the preliminary design are illustrated in Figure 4-15. The urine feed is controlled by the incipient flooding sensor, which turns off the feed pump when it detects liquid carry-over from the wick. Normal control is resumed after a preset time interval that allows the sensor to dry out. The wick is considered expended when the process rate cannot be maintained above a preset minimum. When this condition is reached, the unit is automatically shut down and a visible indicator is actuated to signal that a wick change is required.

An elapsed time indicator is calibrated with the metering feed pump to provide a urine feed totalizer. The condensate control is calibrated to batch a measured quantity of condensate with each actuation of the drain valve. Each batch is recorded by a counter, thereby providing a condensate totalizer. Alarms or automatic shutdown are provided for low air flow, high/low water temperature, and air heater overtemperature.

AIR EVAPORATION/DISTILLATION
CONTROLS AND FAULT ISOLATION

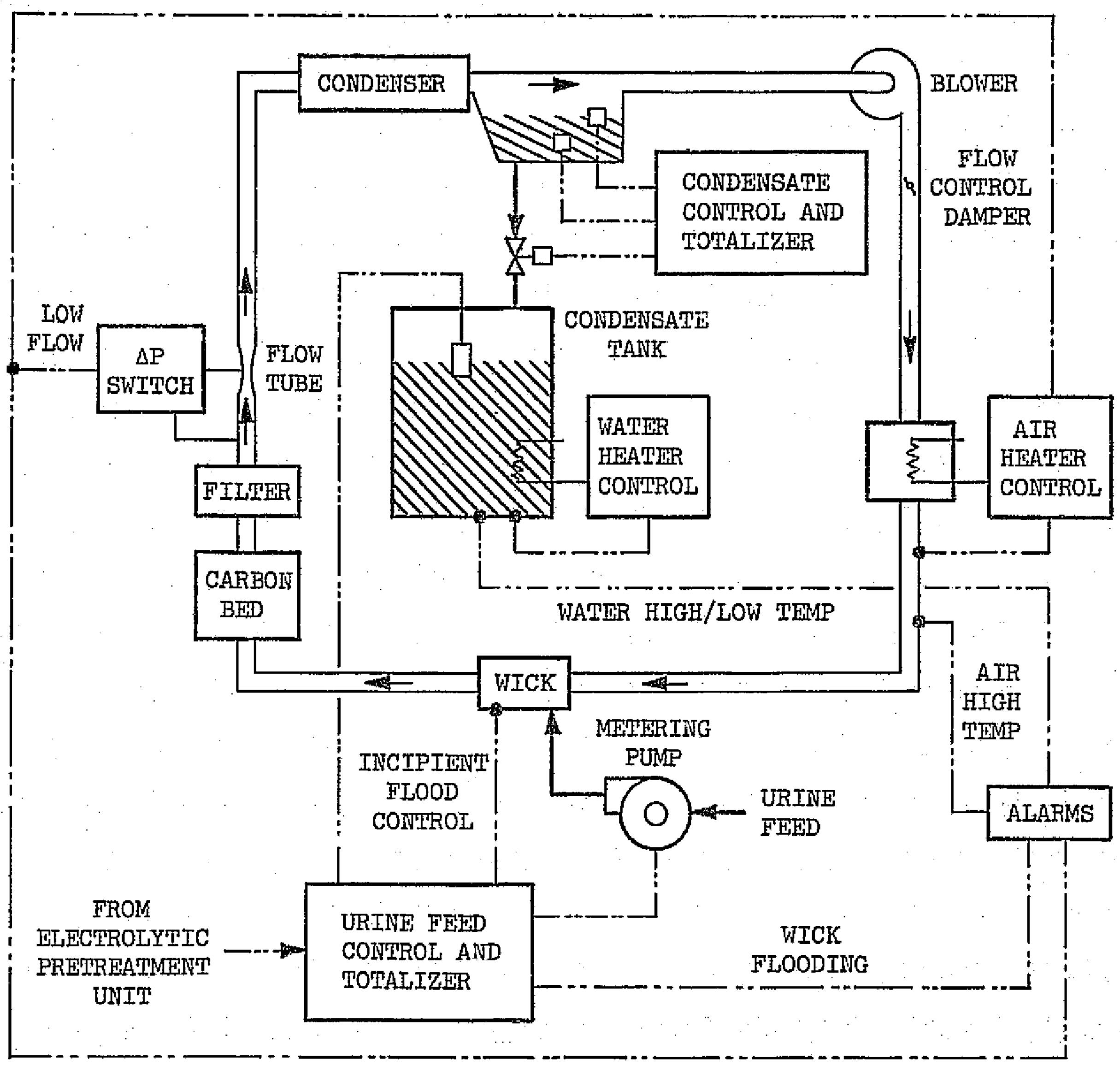


Figure 4-15. Preliminary Design of Control and Fault Isolation for Air Evaporation Unit

4.2.6 Wick Package Concepts

Careful attention was given to man-machine interfaces during the preliminary design of the air evaporation unit. The basic man-machine considerations for the AEU were identical to those previously discussed for the EPU. However, the wick package design is unique to the AEU and the man-machine considerations for its easy removal and replacement without contaminating a spacecraft with toxins were important in the design.

After a conceptual evaluation, two wick package concepts were selected for further study. In the concept illustrated in Figure 4-16, the wick package has a wedge shape, fits into a correspondingly shaped structure built with the air duct, and is secured in position by quick-operating clamps. Sealing is effected by the wedging action and integrity of the seal is ensured by the rigidity of the mating structure.

The concept for a wick package shown in Figure 4-17 uses a quick-release clamp to secure the replaceable item in the air duct and, in coordination with sealing gaskets, to prevent air, liquid, and odor leaks. The sealing gasket shown is integral with the replacement package. Both ends of the replacement package are equipped with a sealing gasket.

After the Preliminary Design Review (Reference 7), a modification of the wedge concept was selected. A metal mockup was constructed and is illustrated in Figure 4-18. In this concept, the wedge shape is incorporated into the shorter-depth dimension, thereby providing better sealing. Additionally, isolation flaps are provided which will permit isolation of the expended wick from the atmosphere during its removal and storage. The concept eleminates the need for external containers to store either new or unused wicks and allows them to be carried in a vehicle in simple racks. The hinged doors also eliminate the necessity of the crew member handling of the expended wicks or exposure to odors from urine residues.

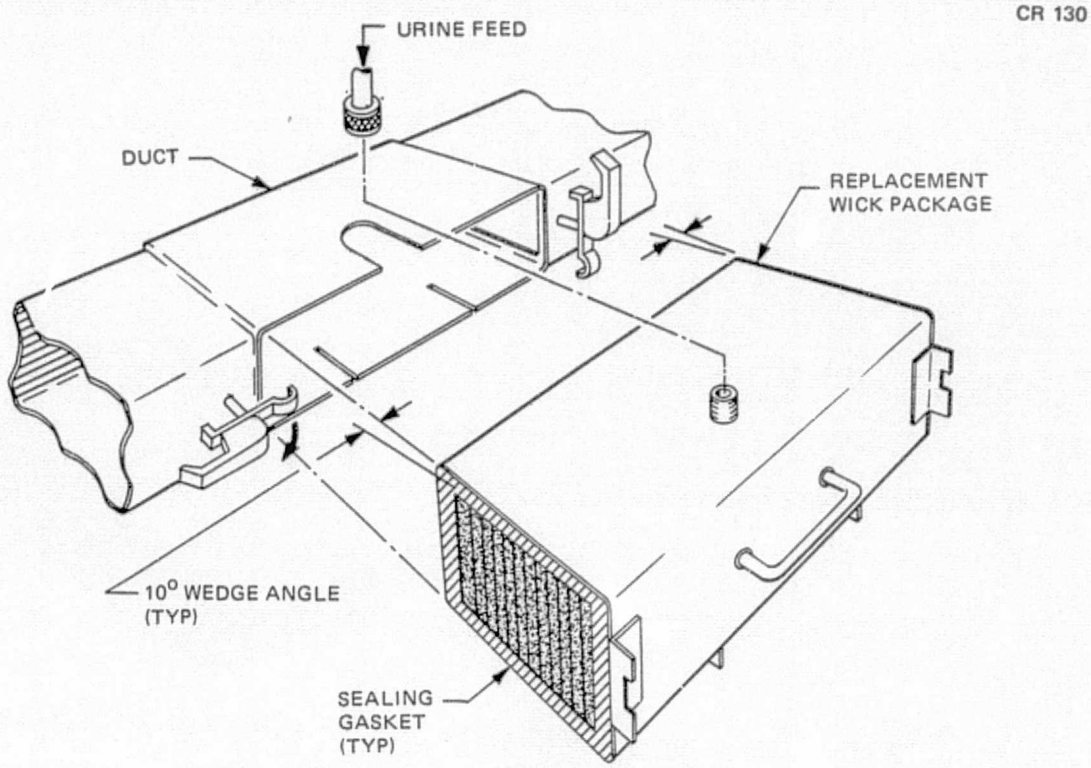


Figure 4-16. Wedge Concept for Replacement Wick Package

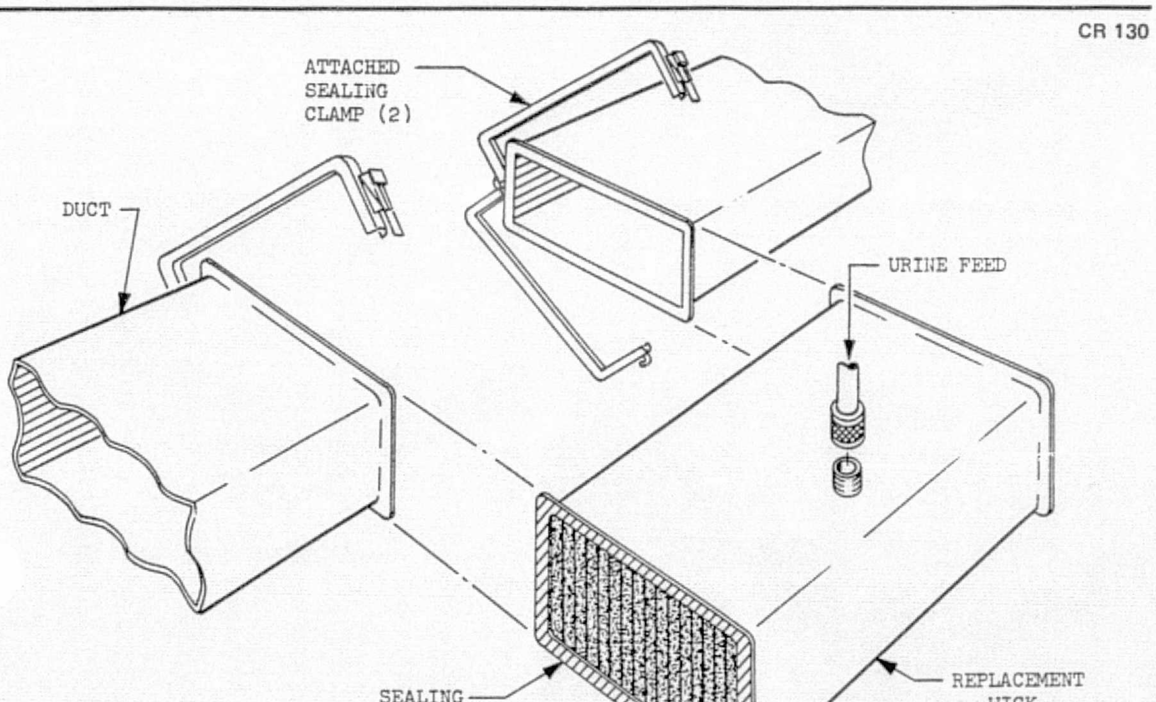
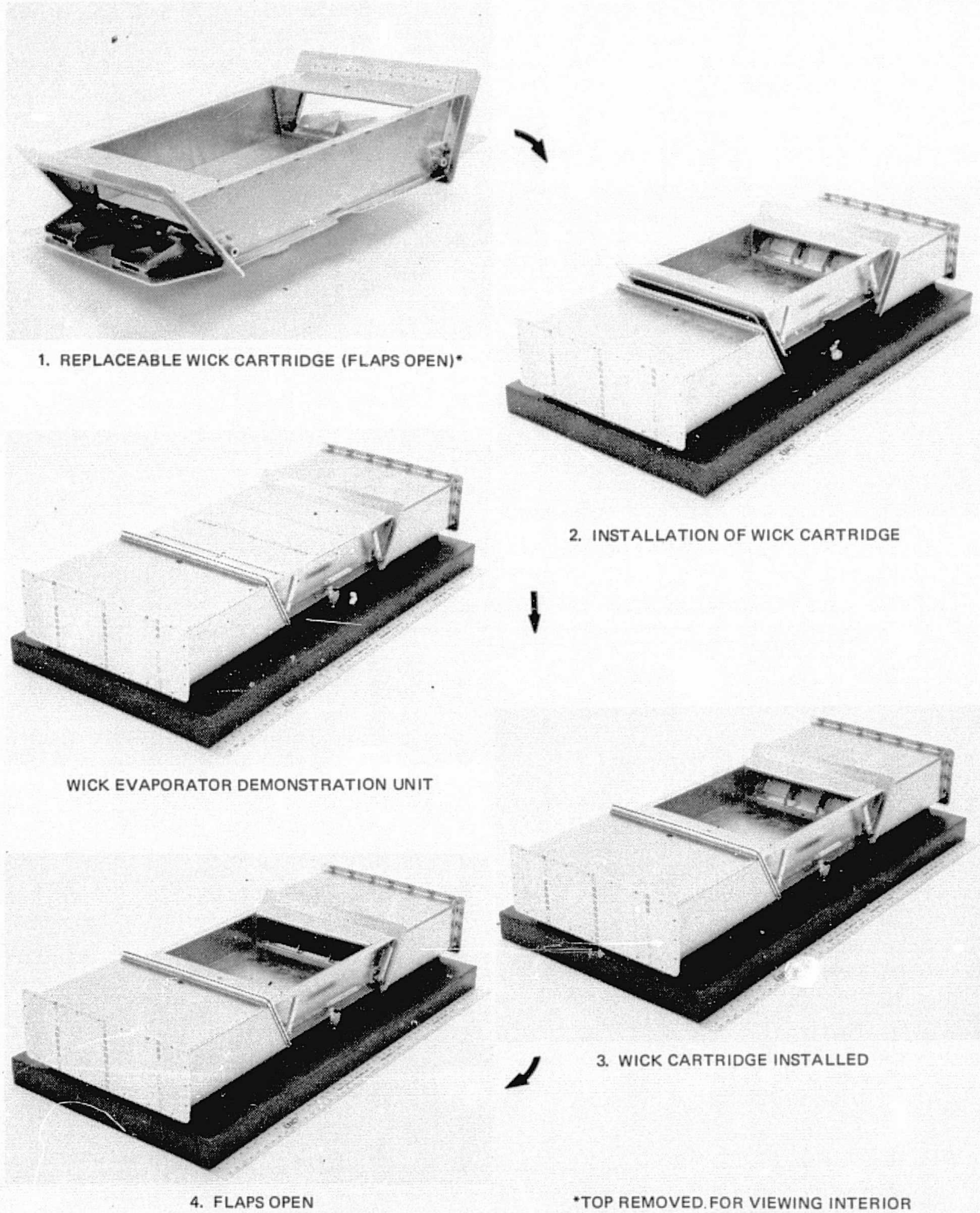


Figure 4-17. Clamp Concept for Replacement Wick Package



1. REPLACEABLE WICK CARTRIDGE (FLAPS OPEN)*

2. INSTALLATION OF WICK CARTRIDGE

WICK EVAPORATOR DEMONSTRATION UNIT

3. WICK CARTRIDGE INSTALLED

4. FLAPS OPEN

*TOP REMOVED FOR VIEWING INTERIOR

Figure 4-18. Replaceable Wick Cartridge Concept Mockup

Section 5
FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

In conjunction with the preliminary design of the EPU and AEU, a study was made of anticipated or possible failure modes and their criticality in terms of operator and crew safety, equipment degradation, quality of reclaimed water, and estimated down-time for repair. This study was used to define the anticipated maintenance requirements, fault detection/shutdown logic, and required monitoring instrumentation. The study attempted to identify any single-point failure that could adversely affect either the crew or the EPU/AEU system.

Attention was directed toward eliminating potential failures that could lead to a premature termination of a mission or test. The methodology for performing the FMECA involved describing the effect characteristics associated with each possible failure mode. The effect characteristics include possible causes, impact on the crew and system, maintenance times, fault detection, criticality classification, and recommended action. Failures were classified in accordance with the resulting effects as follows:

Class	Effect
1	Fatal to one or more crew members
2	Immediate abort
3	Corrective action required; mission termination may result if alert levels are exceeded
4	Alternate, backup system utilized or corrective maintenance required
5	System performance degradation incurred, no requirement for correction

The analysis showed that there will be no Class 1 or Class 2 failures. Class 3 and Class 4 failures served as a basis for determining the fault detection/shutdown logic and required monitoring instrumentation. Class 3 and Class 4 failures may be used for maintenance provisioning or for setting

requirements for redundancy for actual space missions or during terrestrial test programs. Class 5 failures result in degraded performance and serve to identify instrumentation and sensors to monitor appropriate performance parameters.

The general results of the FMECA indicate that the single most prominent Electrovap failure mode is leakage, which could cause objectionable odors and possibly liquids to enter the space vehicle. The components most likely to fail include the pumps, logic controllers, electrolytic cell, feed control, and blower. The complete FMECA is provided in Appendix A.

Should the development of the Electrovap system proceed to flight status, additional engineering reliability analyses should be performed. These analyses should include system simulation by a dynamic computer model to more accurately predict system behavior under a wide range of conditions. This type of simulation would enable the assessment of the impact of multiple failures, failure/repair cycles, and maintenance times on system performance.

Section 6
DETAILED DESIGN

The preliminary designs prepared for the EPU and AEU were presented to NASA personnel on October 3 and 4, 1972 in a Preliminary Design Review at MDAC. The material presented at the review is described in Reference 7. A list of action items for further study was prepared as a result of the preliminary design review, and the results of the most significant of these studies are included in the text of this section. Work on the detailed design of the EPU and AEU was started after approval of the preliminary design by NASA-JSC.

6.1 ELECTROLYTIC PRETREATMENT UNIT DETAILED DESIGN

6.1.1 Design and Layout

The detailed design of the EPU implemented the objectives established in the preliminary design phase. The components are designed and arranged for easy access and quick disassembly for inspection and monitoring of long-life performance. The major dynamic components and the control/status display panel are mounted on the front of the unit (Figure 1-1).

A rear view of the unit is shown in Figure 6-1. The urine storage, electrolysate, and pretreated urine storage tanks are mounted on the back of the center panel.

The control/status display panel is shown in Figure 6-2. The control relays are mounted on the upper left of the panel, and each visible relay is equipped with a display light to indicate when it is energized. The resulting light pattern provides a visual display of the unit status and aids fault isolation and troubleshooting tasks. Each significant electrical circuit in the unit is provided with an individual fuse, mounted below the relays and changeable from the front of the panel. When a fuse fails, a relay is activated which shuts down all power to the unit and lights a display lamp. Also, a flag built into

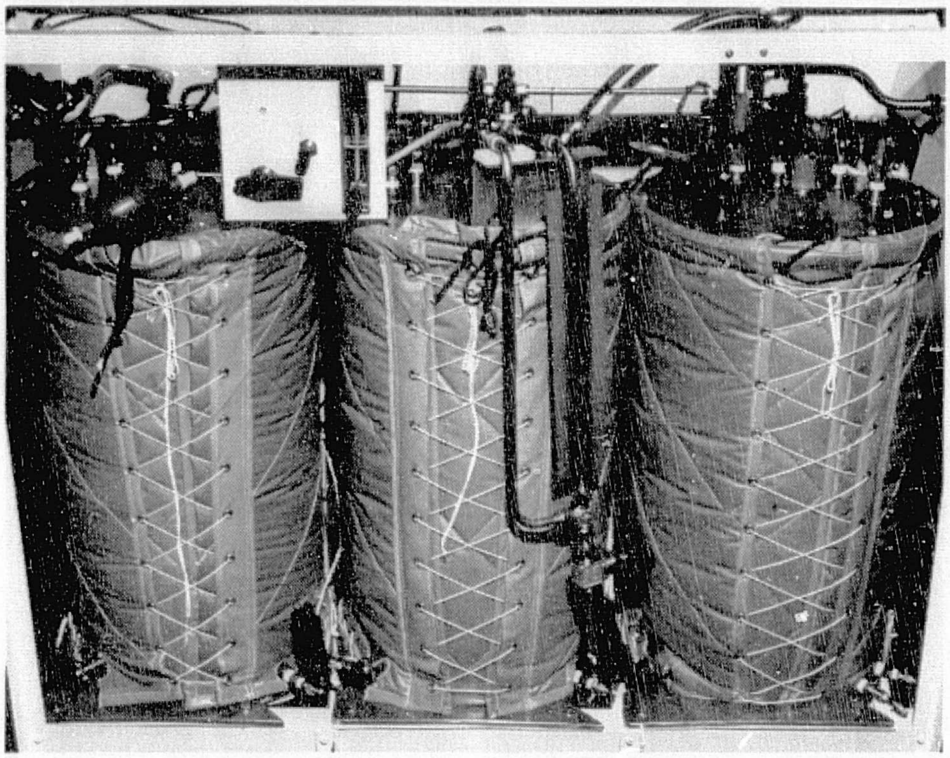


Figure 6-1. Rear View of Electrolytic Pretreatment Unit Showing Tanks

the fuse is automatically displayed, indicating which fuse has fuse has failed. The temperature display and oxygen sensor controls and display are located in the next segment of the control panel.

The tank level display is located to the right of the temperature and oxygen displays. The approximate liquid level in each tank is indicated by an individual three-light display for quick reference. A multiplexed level indicator is also provided to allow a more accurate reading of the level. The process timer and other controls are located on the right side of the control panel.

The control/status display panel is hinged to allow rapid access to the rear of the panel. Figure 6-3 shows the hinged panel in the raised position and illustrates the accessibility of the design for maintenance. Components are grouped in functional modules for ease of assembly and maintenance. Modules include the relay/logic package, level sensor package, cell polarity interchange package, and the oxygen sensor package. Each module may be readily

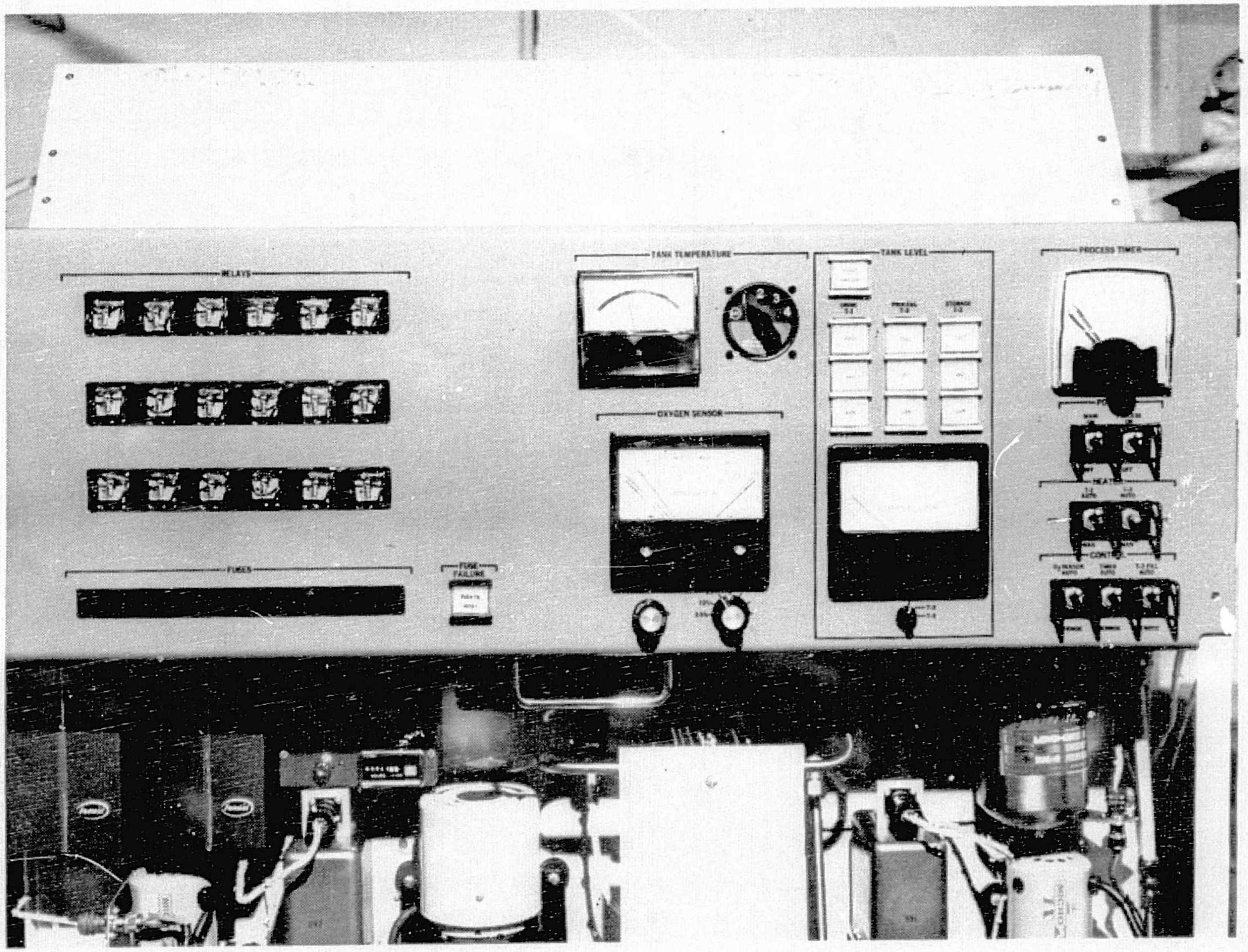


Figure 6-2. Control/Status Display Panel

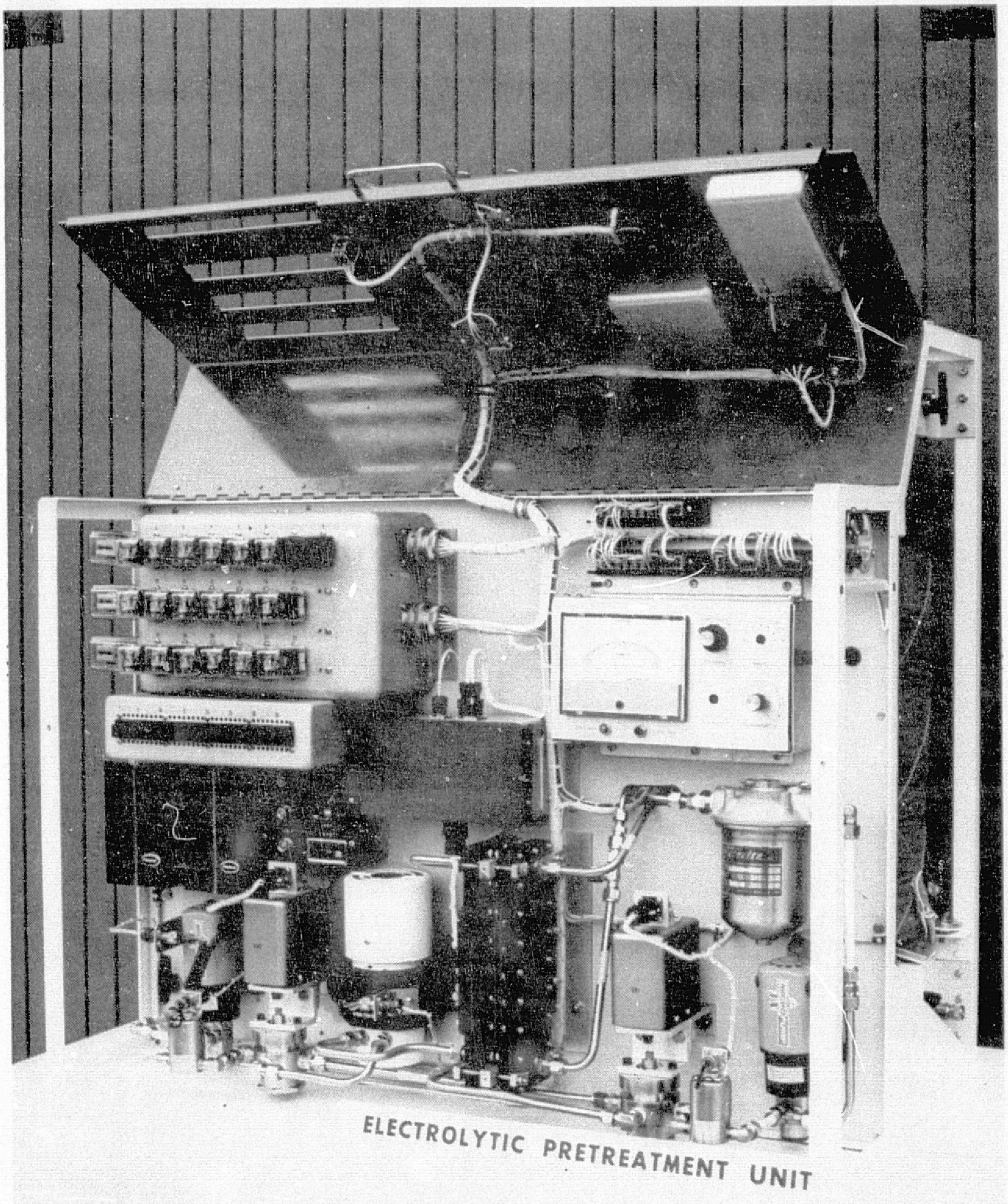


Figure 6-3. Front View of Electrolytic Pretreatment Unit with Control Panel in the Raised Position

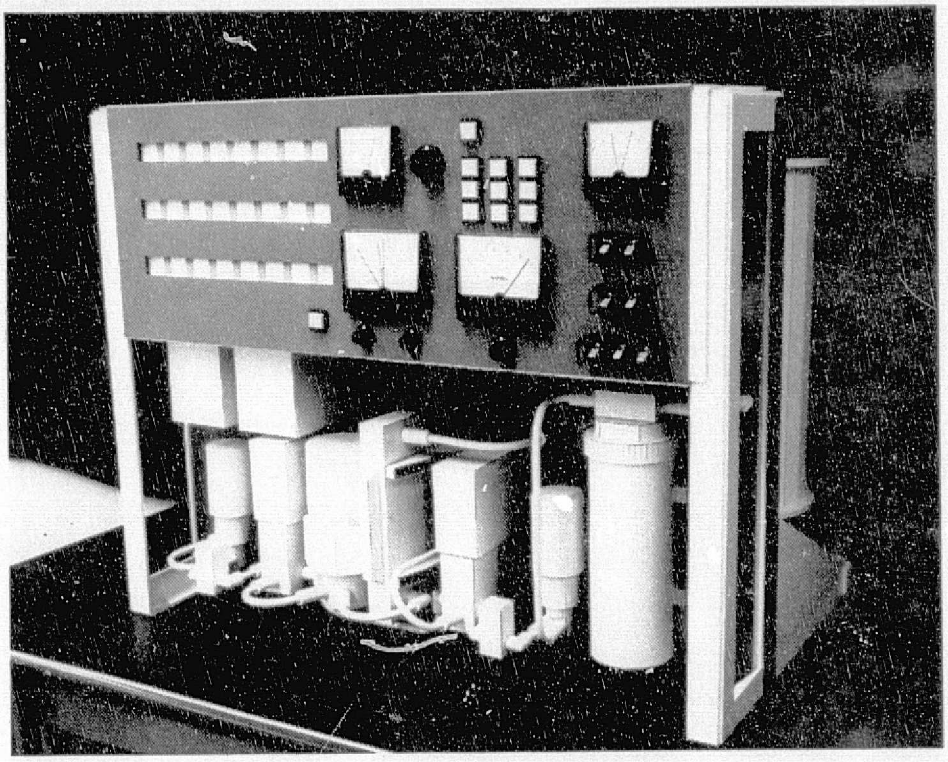
removed from the unit for troubleshooting or repair. The modular packaging also allows the unit to be assembled in several relatively simple tasks rather than in one complex job

Electrical connectors have been provided on individual modules and most electrical components to allow ease of replacement without need for rewiring. (Spare parts must, of course, be of the same configuration as the part to be replaced.) Dynamic mechanical components have been mounted on vibration isolating mounts and are equipped with common-sized, one-quarter-turn fasteners. The use of fluid-line quick-disconnects was evaluated in the design, but the disadvantages inherent in quick disconnects (i.e., propensity for leaking, high pressure drop, and longer during tubing runs) were considered to outweigh the potential benefits. Nearly all components may be changed with only limited amounts of liquid lost and without emptying any tank. Components that cannot be changed without draining the tank are the process loop outlet motor-actuated valve, the tank sample valves, tank isolation valves, tank heaters, and tank temperature sensors.

Figure 6-4 shows a comparison of the EPU soft mockup and the completed unit. Only minor changes were made to the unit configuration in the detailed design. The tank size was increased to accommodate the liquid level sensors selected in the final design, necessitating the raised rear-top cover, and the electrolysate filter housing size was reduced, allowing additional space between components. The reproduction of the mockup configuration in the final unit configuration (Figure 6-4) indicates the usefulness of the mockup technique for system design.

6.1.2 System Description

The finalized EPU mechanical flow schematic is shown in Figure 6-5. Urine and flush water are processed in 28-lb batches in the electrolytic pretreatment loop. On completion of processing, the pretreated urine is transferred to the pretreated urine storage tank. A raw urine storage tank is provided, permitting the unit to start a new electrolysate batch automatically immediately after the previous batch is completed.



MOCKUP

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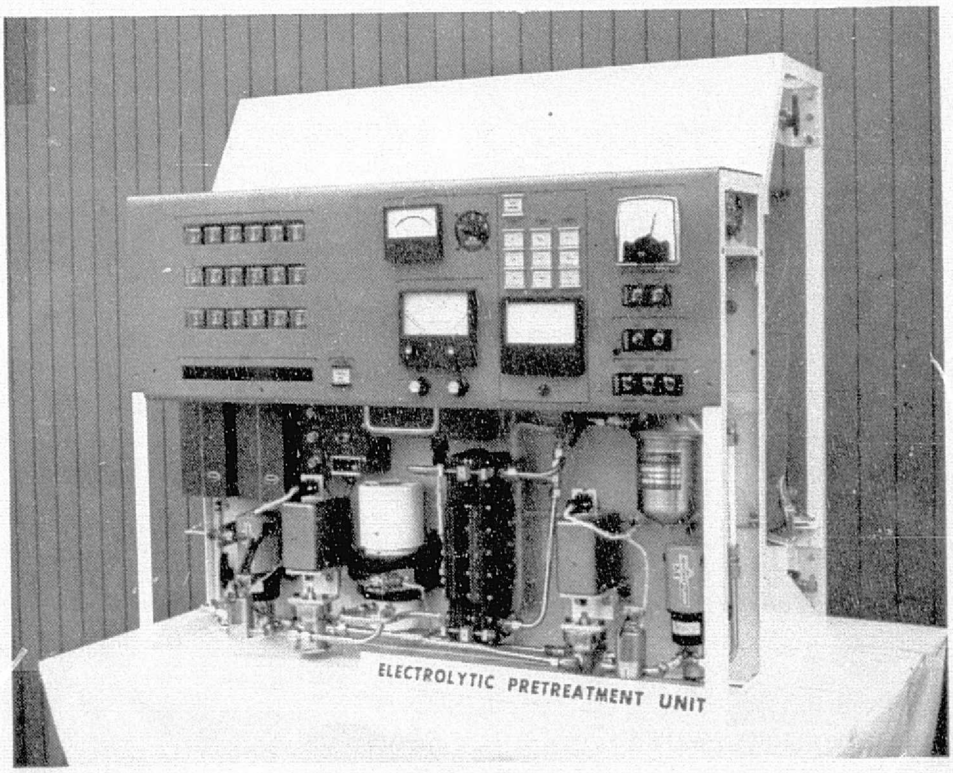

COMPLETED UNIT

Figure 6-4. Comparison of Mockup and Completed Electrolytic Treatment Unit

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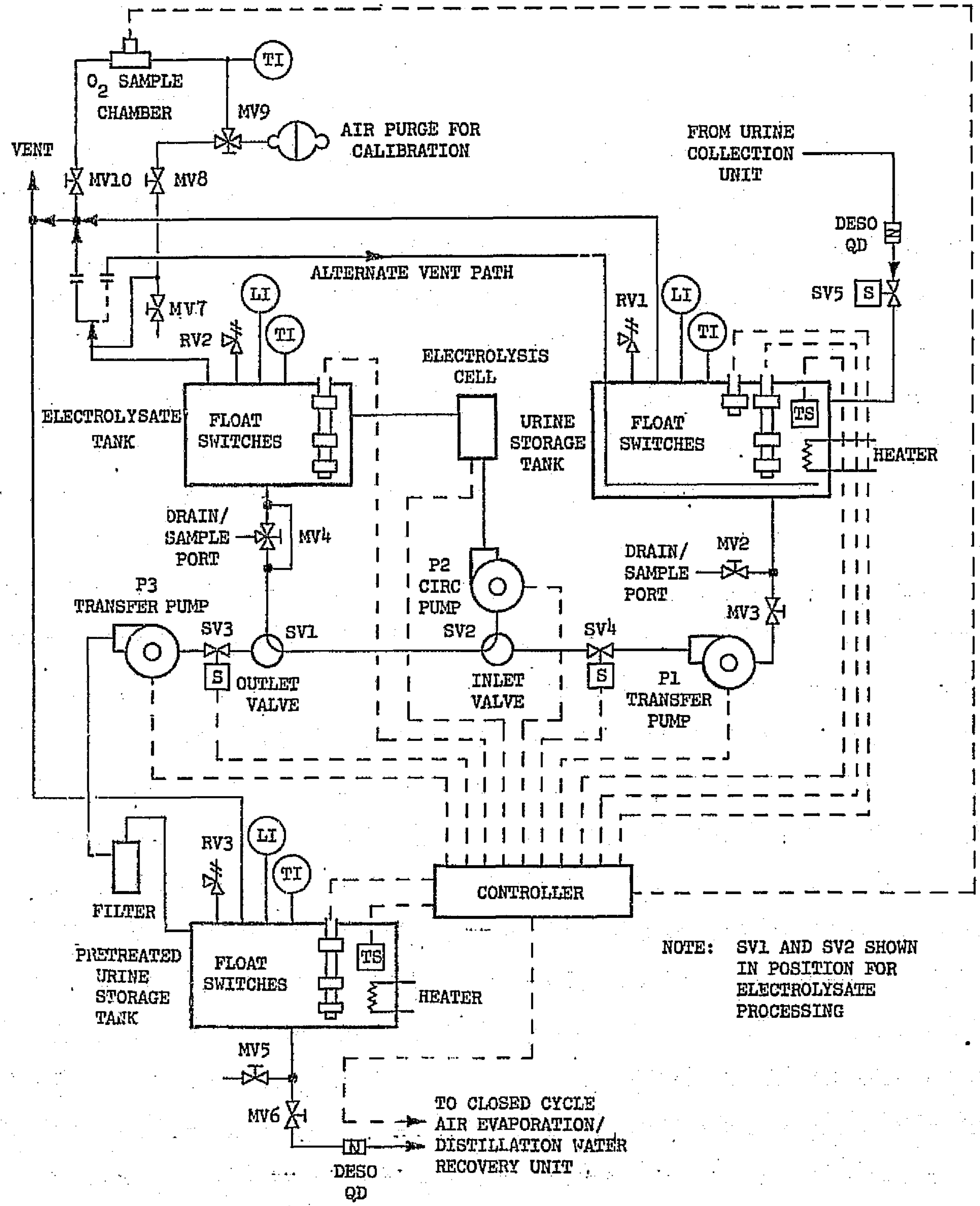

Figure 6-5. Final Design Schematic of the Electrolytic Pretreatment Unit

Each liquid tank is provided with a rubber septum through which a needle can be inserted in the tank to obtain samples for microbial analysis. A wad of cotton containing a biocide may be inserted in the space between the septum and the outer cover to produce asceptic sample collection.

Plug valves are used as inlet and outlet valves for the electrolytic pretreatment loop to avoid stagnant dead-ends in the circulating electrolysate. All operations, except for filling the raw urine storage tank, are completely automatic. Float switches in the tank provide information on the liquid level to the automatic control system, and the liquid level status for each of the tanks indicates to the automatic control system whether a liquid transfer involving any two of the tanks can or cannot occur. Liquid-level information is combined with other sensed information (from the batch timer, oxygen analyzer, etc.) by interconnected relays to formulate an order or series of orders to the operating components.

In operation, the inlet plug valve (SV2) moves to the fill position when a batch of raw urine is available in the raw urine storage tank (T1). The urine shutoff valve (S V4) opens, and the transfer pump (P1) transfers the urine into the electrolysate tank (T2). Valve SV2 then returns to the circulate position, valve SV4 closes, and transfer pump P1 is shut off.

When the electrolytic pretreatment loop completes a batch (determined by signals from the batch timer and the oxygen sensor) and there is room in the pretreated urine tank (T3), the outlet plug valve (SV1) moves to transfer the batch to tank T3. The electrolysate shutoff valve (SV3) then opens, and transfer pump P3 transfers the finished electrolysate into tank T3. Outlet plug valve SV1 then returns to the circulate position, electrolysate shutoff valve (SV3) closes, and transfer pump P3 is shut off.

The secondary water recovery unit may then automatically withdraw the pretreated urine from tank T3 and process it into potable water. When the liquid level of the pretreated urine tankis too low, a float switch in tank T3 shuts off the secondary water recovery unit until more pretreated urine is available.

A more complete description of the electrolytic pretreatment unit operation and the function of individual components may be found in Reference 8.

Control logic in the unit is provided by commercially available electromechanical latching and nonlatching relays. In establishing the logic design, a detailed analysis was made which entailed a conceptual design of both relay and solid-state systems. A comparison of the power, weight, and volume required for relay logic versus solid-state logic is given in Table 6-1. The large relay design was selected for the following reasons:

A. Relatively high power losses are associated with the solid-state switching functions.

B. Solid-state memories are volatile—i. e., they fail to return to their proper state after power loss, unless a separate local battery is provided.

C. The convenience of indicator lamps to display logic status built into the large relays is a considerable benefit to the unit operator.

D. The miniature relays require more rigid power regulation than the large relays, and have limited capabilities to switch the relatively high currents present during pump and servo motor start-up.

It is interesting to note that the relay logic circuit selected requires less than half as much power as the solid-state logic circuits. This is primarily because the solid-state circuits require a power supply that dissipates considerable energy.

Table 6-1

COMPARISON OF POWER, WEIGHT, AND VOLUME FOR SOLID-STATE VERSUS RELAY LOGIC SYSTEMS

Item	Solid-State	Large Relays	Miniature Relays
Switching power (w-hr/day)	405	65	65
Logic power (w-hr/day	221	114	80
Total power (w-hr/day)	626	179	149
Total weight (lb)	4.1	10.2	6.1
Total volume (ft^3)	0.128	0.372	0.252

6.1.3 Control Functions

A summary description of the EPU control functions is given in the following text. Additional information may be found in References 7 and 8.

Float Switches—The float switches are magnetically actuated reed-type switches. They are mounted inside a sealed tube immersed in the liquid, and are actuated by magnets mounted in floats concentric to and outside of the tubes. The float switches provide information signals on liquid quantity to the control logic circuits. In addition to their control functions, all float switches display the liquid level status by operating separate panel lights.

Timer—The timer determines the minimum duration of the electrolytic process. It serves as a backup for the oxygen analyzer/controller to ensure that incompletely processed batches cannot be transferred to the pretreated urine tank. A latching relay provides a nonvolatile memory to prevent resetting the timer should a power loss occur after the preset timer period of operation.

Oxygen Analyzer/Controller—The percent of oxygen produced in the by-product gas stream during electrolysis of urine increases as the organic materials in the urine are depleted by the electrolytic oxidation process. Figure 6-6 shows the total organic carbon reduction and the electrolysis gas oxygen content as a function of time during pretreatment of 4-liter urine batches. The percent of evolved oxygen is a reliable indication of the completion of organic conversion, and is used to control the electrolytic pretreatment end point. An oxygen analyzer is used with a polarographic sensor. The oxygen content of the gas stream is displayed on a meter mounted on the control panel and equipped with adjustable high and low set points.

At the beginning of a batch, the gas in the electrolysate tank contains a high percentage of oxygen. As the new batch processing proceeds, this oxygen is flushed out by gases generated in the electrolytic cell which contain very little oxygen. This causes the oxygen content of the gas in the electrolysate tank to fall below the low-range set point of the oxygen analyzer/controller and activate a latching relay. As the processing proceeds and organic material in the urine is depleted, the oxygen content of the gas in the elec-

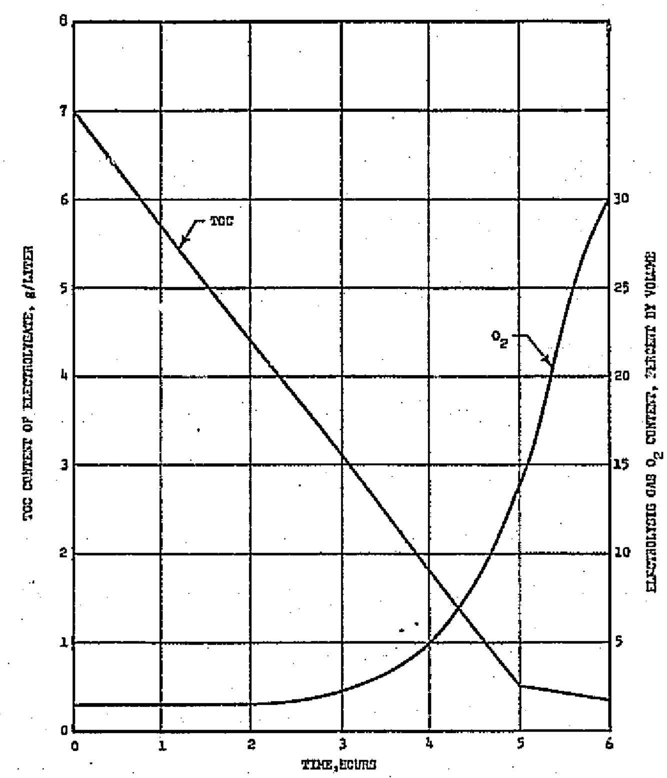

Figure 6-6. Variation in Electroysate TOC and Electrolysis Gas Oxygen Content with Processing Time

trolysate tank rises above the high set point. The batch is then ready for transfer to the pretreated urine tank provided the timer has reached the end of its cycle. The high and low oxygen latch relays are reset when the electrolysate tank is filled with raw urine.

A typical elapsed time setting for the batch timer and the low and high set points for the oxygen analyzer/controller are shown in Figure 6-7. In normal operation, the batch timer is set for the minimum time required to process a batch. The oxygen analyzer/controller will normally hold the batch for longer processing.

Heater Controllers—Heaters are installed in the urine storage and pretreated urine storage tanks to control microbial growth. The heater controllers maintain the desired tank temperatures. Temperature indicators independent of the temperature controller sensors are provided in each tank for temperature readout. If desired, the tank heaters may be controlled automatically so that heater action is inhibited should the liquid level in the heated tank fall below the low float switch activation point.

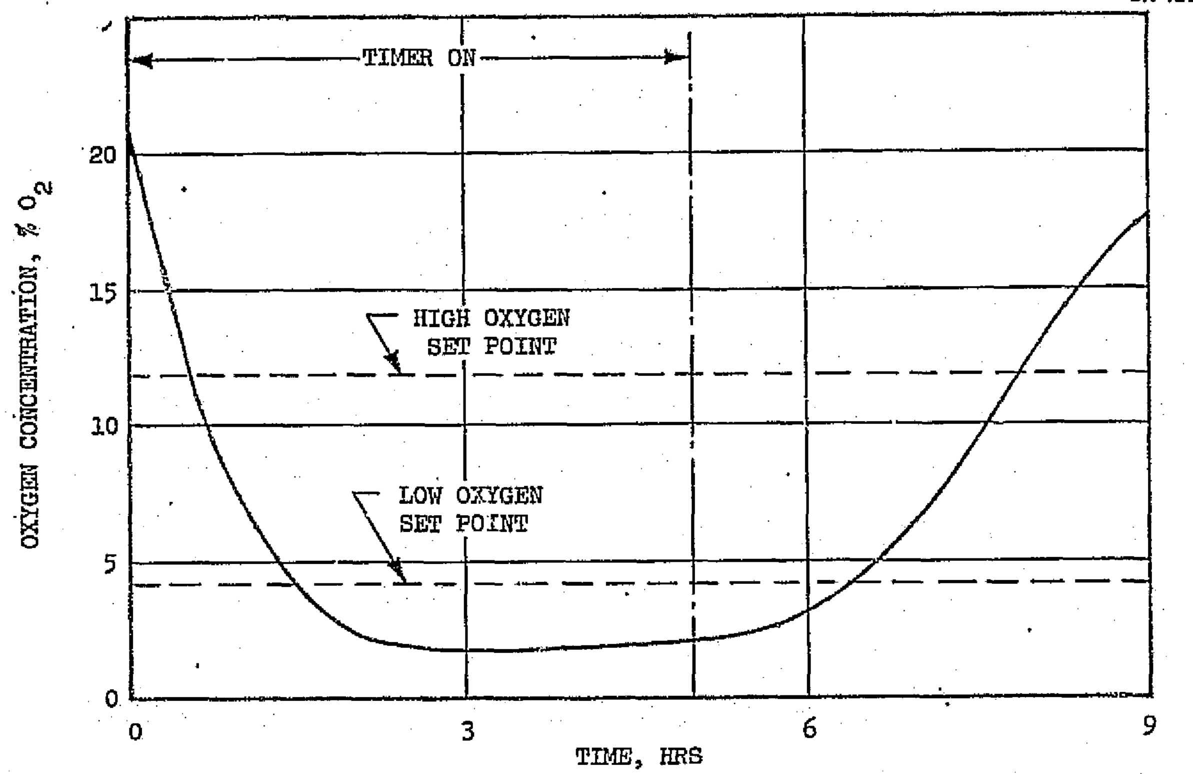

Figure 6-7. Typical Timer Duration and Oxygen Analyzer/Controller Settings

Main Power Switch - The main power switch shuts off all power to the unit when in the off position except for the timer clutch power. This switch may be used for emergency shutdown control.

Process Power Switch - This switch controls the circulation pump, the electrolysis cell power, and the timer motor. It allows other unit components to remain on-line, but does not allow batch processing when in the off position.

Oxygen Sensor Override - This control allows the polarographic oxygen sensor control function to be bypassed. It is a momentary switch and requires a separate positive actuation of the control for each batch transferred before the low and high oxygen setpoints are reached.

Timer Override - This control allows a batch to be reprocessed by resetting both the timer and the oxygen setpoints. A positive switch actuation is required for the reprocessing of each batch.

Electrolysate Transfer Control Switch - This momentary switch control allows transfer of processed electrolysate to the pretreated urine storage tank to be initiated even though the storage tank liquid is above the mid-level float switch actuation point.

6.1.4 Component Selection and Drawing Preparation

Components were selected in the detail design phase and sufficient detailed working and assembly drawings were prepared to permit fabrication and assembly of the EPU. The drawings prepared for the EPU are listed in Table 6-2. Reduced copies of these drawings maybe found in Reference 8.

Components selected for use in the EPU were evaluated to ensure that they were compatible with the design requirements. Such factors as performance, power consumption, reliability, size, weight, volume, and noise level were considered in making the final component selections.

6.1.5 Fabrication and Assembly

Major components of the EPU were fabricated on a schedule designed to permit a logical assembly sequence. The frame and control panels were fabricated and major components mounted to ensure a correct fit. The components we~~re~~ then removed and parts requiring surface protection were

Table 6-2

ELECTROLYTIC PRETREATMENT UNIT DRAWING LIST

Drawing No.	Title
1T44333	Electrolytic Pretreatment Unit
1T44375	Frame Assembly, Electrolytic Pretreatment Unit
1T44406	Storage Tank Assembly
1T44422	Electrolytic Cell
1T44477	Control Panel, EPU
1T44478	Relay Box, EPU
1T44675	Schematic, Electrical, EPU
1T44676	Schematic, Mechanical, EPU

painted or Teflon-coated. All components were then permanently assembled and the electrical wiring of the unit completed.

6.1.6 Envelope Dimensions and Weight

The envelope dimensions of the EPU are 38 in. wide by 35 in. high by 22 in. deep. This envelope contains all components of the unit, including the urine and pretreated urine storage tanks which could be mounted remote from the unit in a flight system. The envelope dimensions of the unit, including the path swept by the hinged control panel in traveling to the access position, are shown in Figure 6-8.

The dry weight of the completed unit is 291 lb. Approximately 40 percent of the weight is accounted for by the three tanks in the system. Due to the use of commercial components and to the selection of material thicknesses biased toward ease of fabrication, it is estimated that the unit weight is approximately 150 percent of that obtainable for a flight unit.

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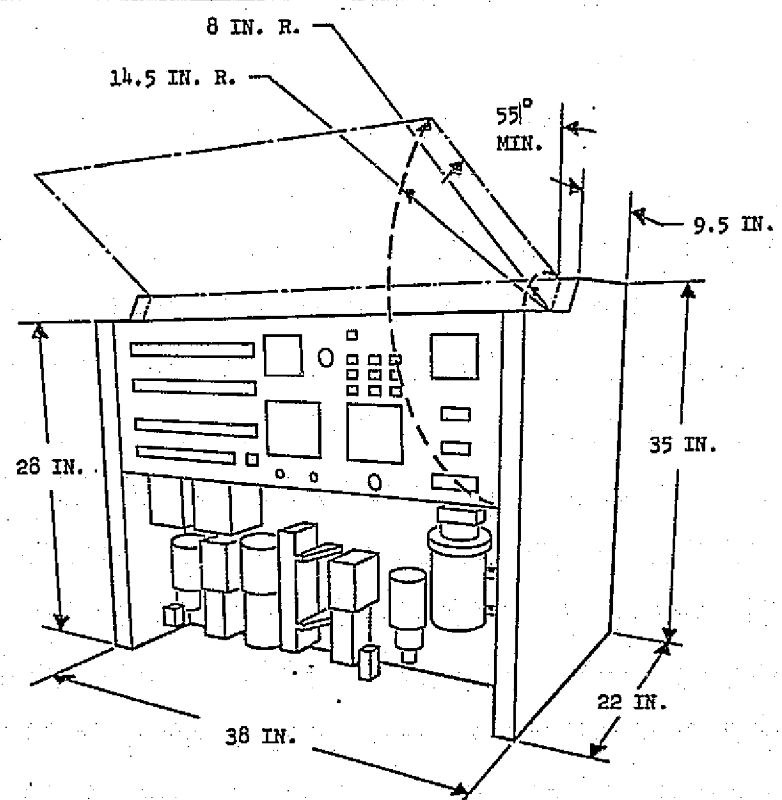


Figure 6-8. Outline Drawing of Electrolytic Pretreatment Unit

6.1.7 Interface Requirements

The electrical and mechanical interface requirements of the EPU are shown in Table 6-3. Direct current is utilized for the two-way solenoid valves and the electrolysis cell, but all other components operate on 120 vac. A switch closure is provided to signal a low level in the storage tank to the downstream final treatment system.

Table 6-3

EPU INTERFACE REQUIREMENTS*

Electrical

- Electrolysis Cell Power
  - 20 to 28 vdc
  - 40 amp maximum
- Controller and Component Power
  - 120 v, 60 Hz single-phase ac
  - 20 amp maximum
- Signal to Air Evaporator (to indicate low level in pretreated urine storage tank
  - Switch closure indicates low level. Contacts rated for 5 amp at 120 vac
  - 0 or 120 vac, 60 Hz supplied to illuminate the low level indicator in the air evaporator. Voltage indicates low level

Mechanical

- Urine and Flush Water Inlet to Unit
  - Female quick disconnect
- Vent for Tanks
  - Tube fitting, 3/8-in. OD
- Pretreated Urine from Unit
  - Male quick-disconnect

*See Reference 8 for mating interface connector part numbers.

Mechanical interfaces are selected to minimize the possibility of improper connection.

6.2 AIR EVAPORATION UNIT DETAILED DESIGN

The detailed design of the AEU implemented the objectives set in the preliminary design phase and incorporated the same design philosophy estabished for the EPU.

6.2.1 Design and Layout

The AEU components are contained in a totally enclosed cabinet (Figure 1-2). The location of major components is shown in Figure 6-9. The enclosure concept minimizes heat loss and provides an effective sound barrier. Additionally, all air-flow components were thermally or acoustically insulated. The acoustical isolation of the blower was a primary concern due to the high-frequency noise problems associated with high-speed aerospace blowers.

The control/status display components are mounted on two hinged panels, which are mounted on the front of the AEU. These two panels are shown in Figure 6-10. A functional control schematic incorporated in these panels (Figure 6-10) provides a visual location of the control/status displays which is useful for fault isolation activities.

Visual display of the system air pressures in the closed loop is provided by pressure gages. Air-flow measurement is provided by a differential pressure gage/switch in conjunction with a calibrated flow tube. Temperature measurements are obtained by means of the thermocouple selector switch and temperature-indicating meter.

The operational status controls in the upper portion of the right-hand panel include the main power control switch, mode status indicator, fuse failure indicator, and elapsed time recorder. The mode status indicator is a split display in which the processing or standby mode is illuminated, depending on the operational condition of the AEU. The fuse failure indicator is illuminated when a system fuse fails and will automatically place the AEU in the standby mode until the malfunction is corrected.

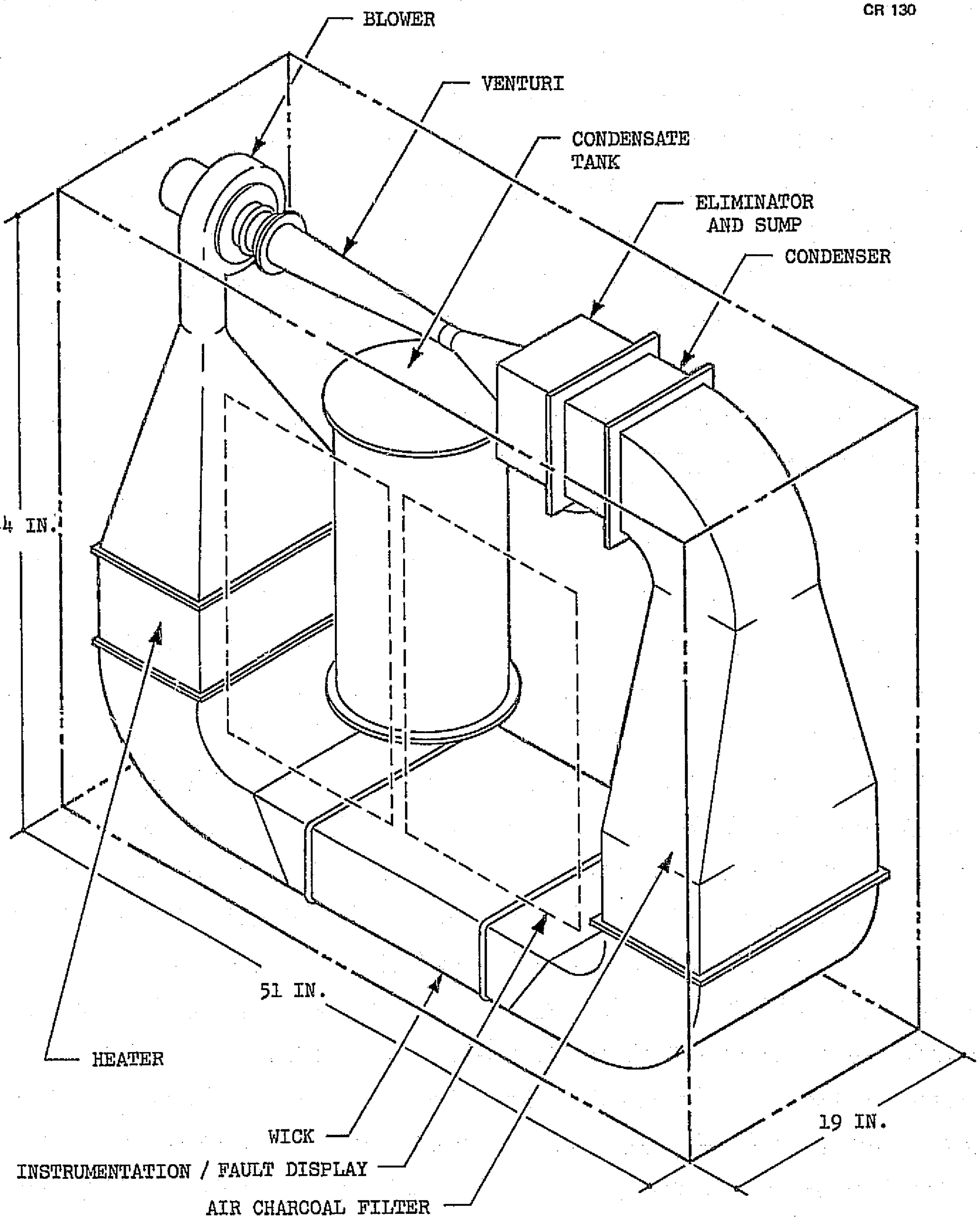


Figure 6-9. Outline Drawing of Air Evaporation Unit

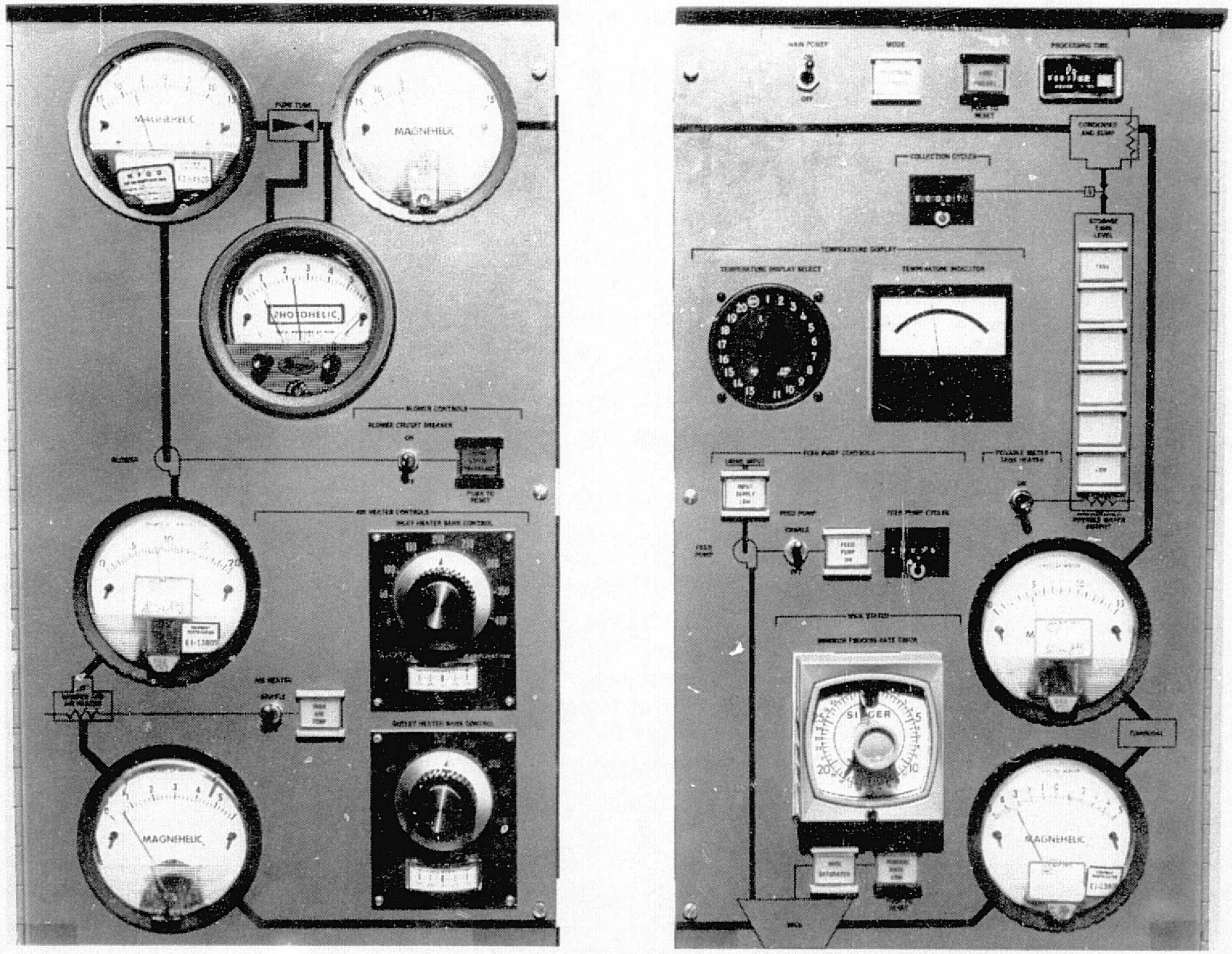


Figure 6-10. Control/Status Display Panels for Air Evaporation Unit

The condensate collection cycle display is located directly below the operational status controls. The condensate collection cycles are recorded by a counter with each actuation of the condensate sump float switches. Each actuation of the counter represents a calibrated quantity of condensate, thereby providing a visual indication of the total condensate collected.

The storage tank control/status displays are located to the right of the condensate collection cycle counter. The storage tank level status is provided by six level indicators which are illuminated by the actuation of six individual float switches in the storage tank. The level indicator labeled "full" also places the AEU in the standby mode. The heater control switch is located to the left of the level status indicators for the storage tank.

The pretreated urine feed pump controls are located in the center of the right-hand panel. The input supply low indicator is illuminated whenever the EPU pretreated urine tank level is low. Actuation of this indicator automatically places the AEU in the standby mode. With the feed pump control switch in the enable position, the feed pumps are automatically controlled by the wick process control. The on-indicator and cycle counter are activated with each feed pump cycle. Each activation of the cycle counter represents a calibrated quantity of pretreated urine, thereby providing a visual indication of the total feed.

The wick status controls are located directly below the feed pump controls. The wick saturated indicator is illuminated whenever the incipient flooding sensor detects liquid in the lower portion of the wick. Activation of this sensor inhibits the feed pump activation until the liquid is evaporated. The process rate low indicator is illuminated and the AEU placed in the standby mode whenever less than 10 feed pulses occur in 30 minutes. The interval is timed by the minimum process rate timer.

The air heater controls are located in the lower portion of the left-hand panel. Two banks of air heaters are controlled by two proportioning temperature controllers. With the air heater control switch in the enable position, the heater controls function automatically, but are overridden by the blower low flow switch. The high air temperature indicator is illuminated when the air temperature rises above a preset limit established by a temperature switch. This switch deactivates both heater controls.

The blower controls are located in the center of the left panel. These controls include the circuit breaker and a flow out-of-tolerance indicator. The flow out-of-tolerance indicator is illuminated and the AEU placed in the standby mode whenever the flow is below a preset minimum established by the flow tube differential pressure switch/gage. Flow control is provided by a damper located as shown in Figure 1-2. A time delay of approximately 20 seconds is incorporated into the low air flow control to permit initial system startup.

The major electrical/electronic components, feed pumps, and potable water storage tank are located in the center of the AEU behind the two control panels. A view of the interior of the AEU with the two hinged panels open is shown in Figure 6-11. The major portion of the AEU controls is located in the control/logic circuit module. This module as well as the major components utilizes electrical connectors for ease of removal and replacement.

The development of the wick package was a major design effort. A disassembled view of the final wick package design is shown in Figure 6-12. This design incorporated the wedge concept evaluated during the preliminary design phase. The incipient flooding sensor is a heated thermistor which activates the wick saturated control function when cooled by liquid. When the wick package is assembled, the incipient flooding sensor is located in a small cavity in the lower portion of the wick. The entire wick package is Teflon-coated for corrosion-resistance. Self-sealing quick-disconnects are provided in the feedline at the AEU/EPU and wick package interfaces.

6.2.2 System Description

The finalized AEU mechanical flow schematic is shown in Figure 6-13. Pretreated urine is metered and fed into the wick where the water is evaporated in the heated airstream. The urine feed rate is established by logic circuits which utilize an adjustable timer and an incipient wick flooding sensor to control the feed pumps. The heated air then passes through the carbon filter and the condenser where the water is removed. The blower then recycles the dehumidified air back through the air heater, where the temperature is increased to the design set point, and back into the wick.

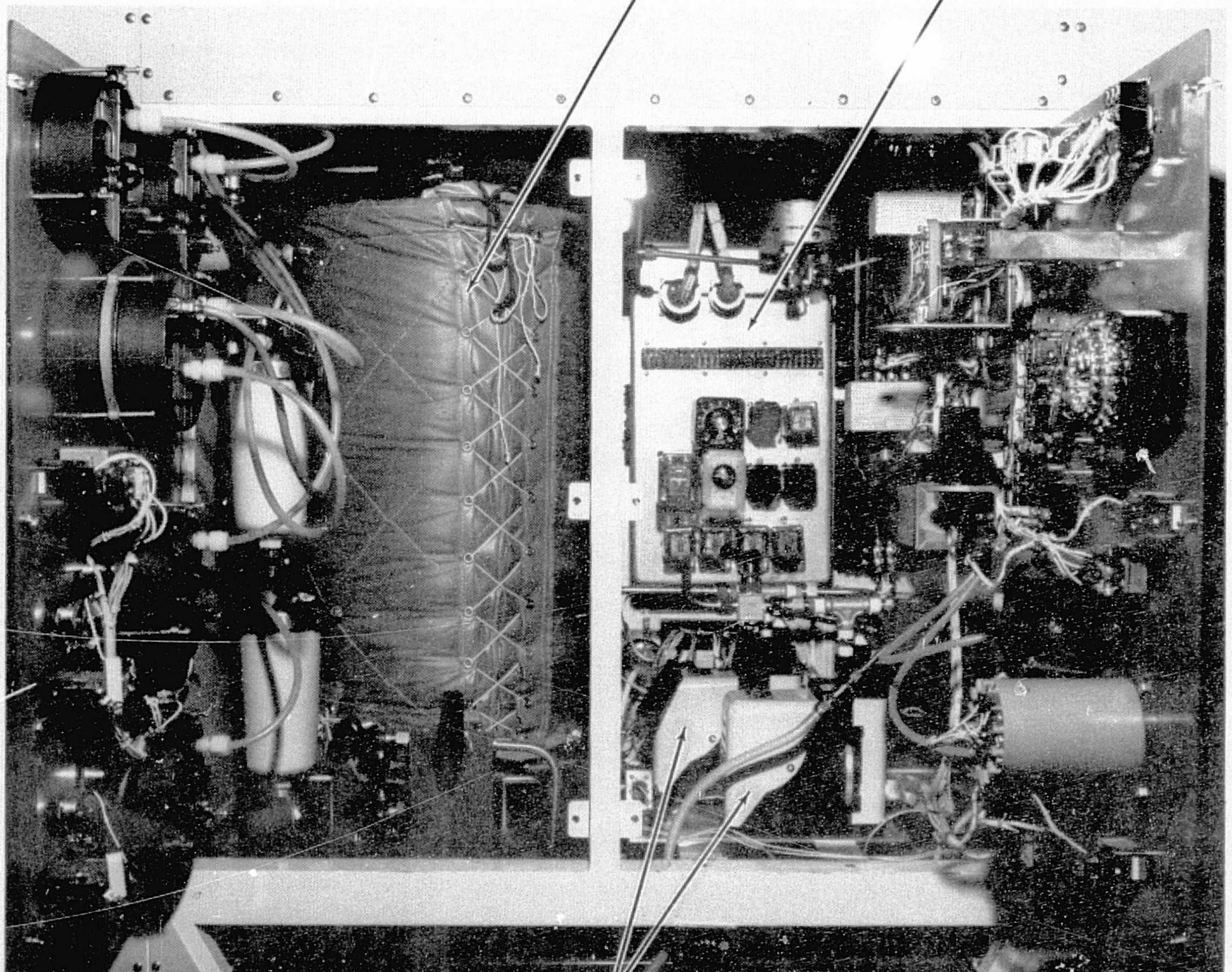


Figure 6-11. Interior View of the Air Evaporation Unit

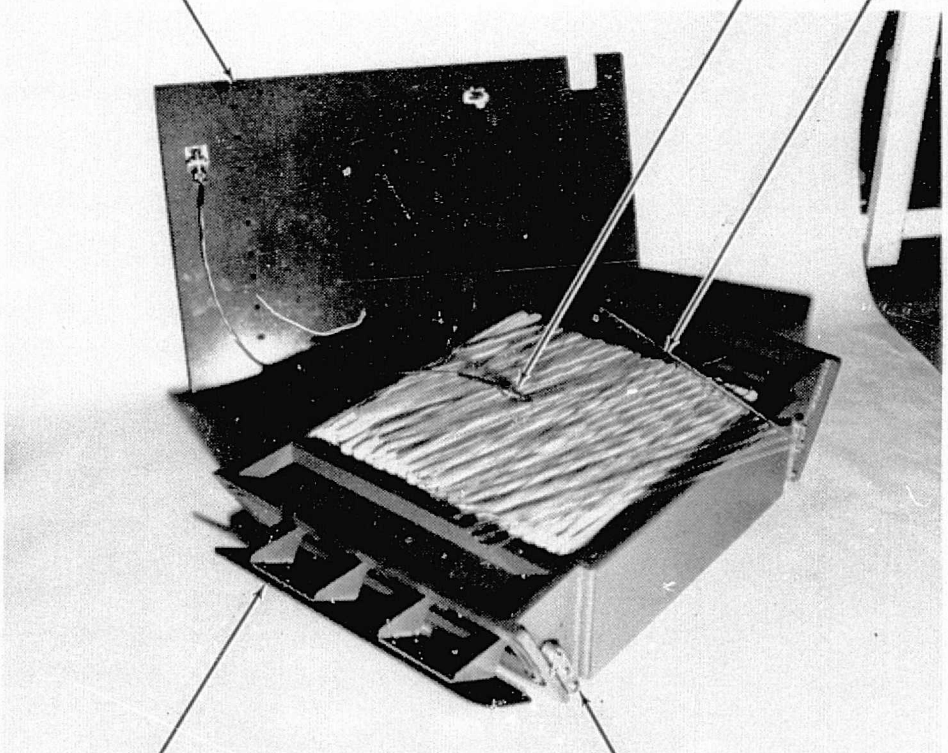


Figure 6-12. Disassembled View of Wick Package

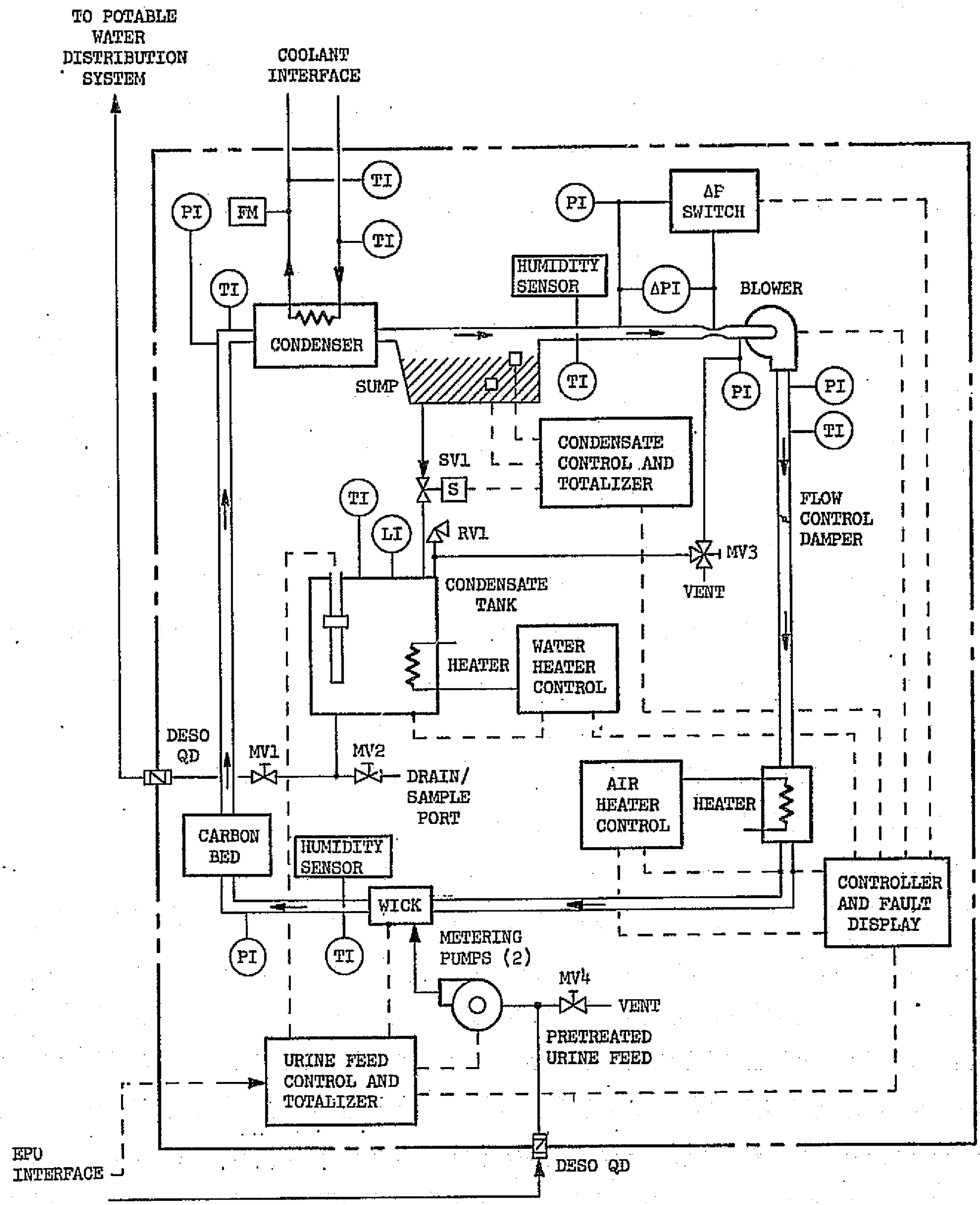


Figure 6-13. Final Design Schematic of Air Evaporation Unit

The system described in Figure 6-13 is essentially the same as described in Figures 4-12 and 4-15 for the preliminary design phase. However, the following changes have been made in the detailed design configuration:

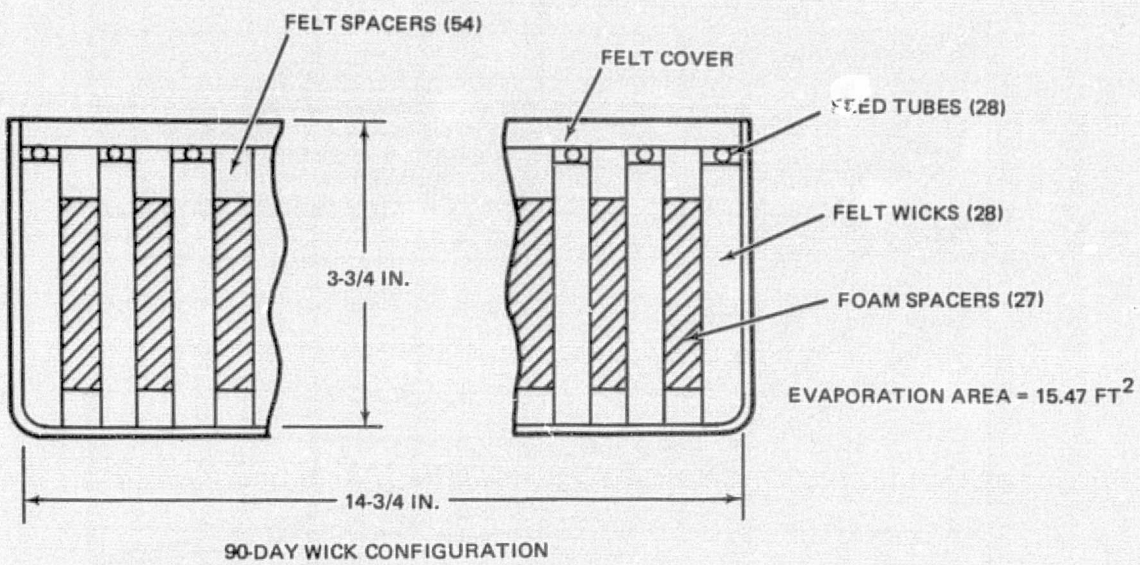
A. The particulate filter downstream of the carbon bed was eliminated, as the coconut shell charcoal used in the carbon bed exhibited very little charcoal dusting. Additionally, since the carbon bed is contained in two Teflon-coated stainless-steel wire screens, the carbon bed was considered an adequate filter. The screens are 30 by 30 mesh with 0.01-in.-diameter wire.

B. The water storage tank high/low temperature alarms were eliminated. It was determined that the automatically controlled storage tank temperature could be adequately monitored on the temperature display. Additionally, this tank would normally be considered as a portion of the water storage and distribution subsystem in a flight water recovery system and the tank and associated controls probably would not be installed in the AEU.

C. The water distribution pump was eliminated. As noted in Item B, the water storage tank was not actually considered an integral part of the AEU. A simple tank drain line was therefore installed.

D. Two urine feed pumps were installed. Bench testing of the urine distribution manifold revealed that the actual pumping flow rate of 250 mliter/min used during the 90-day test (Reference 4) was not adequate for uniform distribution in the wick package. The two pumps, which are installed in parallel, provide a maximum flow rate of 450 mliter/ min, providing very good wick distribution.

E. The final design of the wick package resulted in a wick with less evaporation area than in the 90-day test design (Reference 4). This loss in area was due to the 3/8-in.-thick PVC-coated urethane foam spacers used in the new design, as opposed to the 1/4-in.-thick uncoated urethane foam spacers used in the 90-day test. Additionally, some wicking surface was lost due to the wick cover flange design. The difference between the two wick cross-sections is shown in Fig- difference between the two wick cross-sections is shown in Fig-ure 6-14. The effect of this reduction in evaporation area was calculated by the same analysis used during the preliminary design phase. The results of this analysis are shown in Figure 6-15. By comparing the design point of 3.22 lb/hr feed at 200°F inlet and an



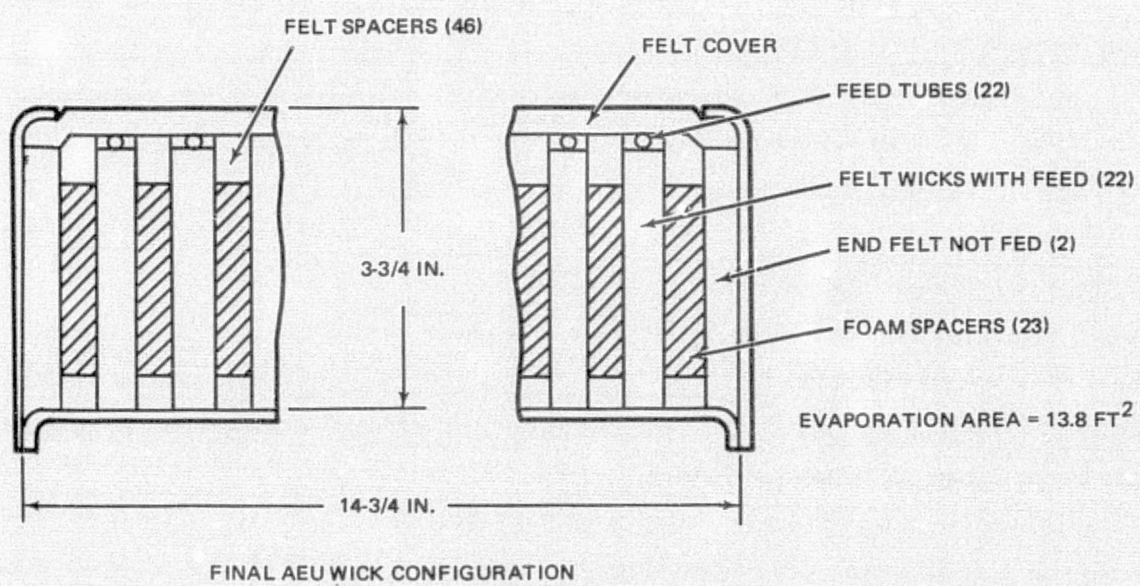


Figure 6-14. Comparison of 90-Day Test and Final Design Wick Configurations

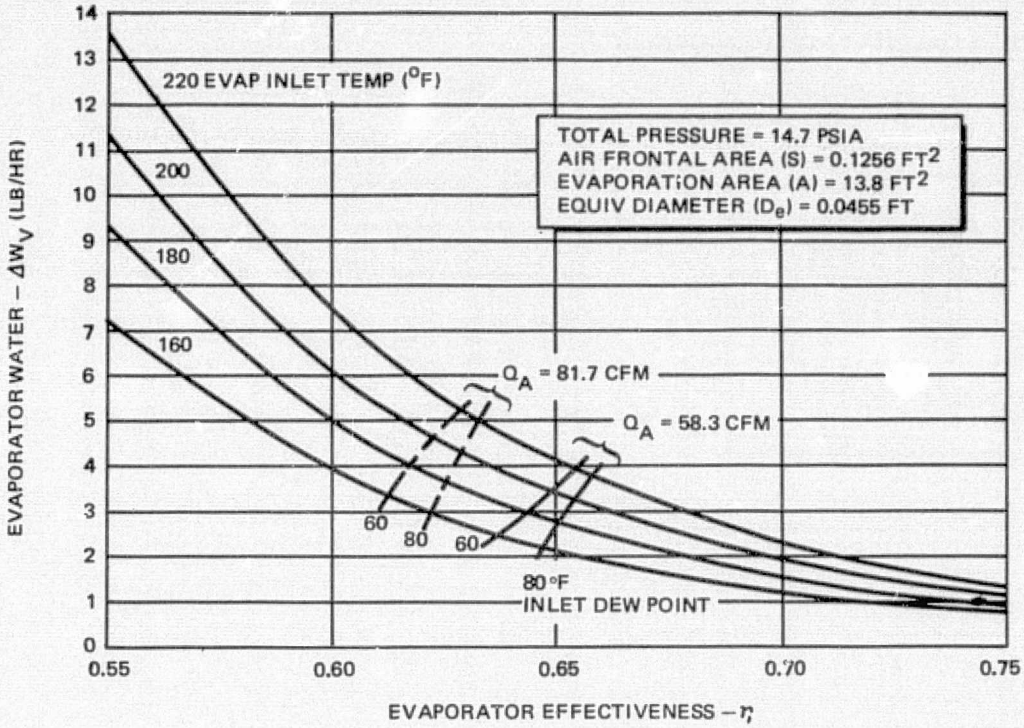


Figure 6-15. Predicted Performance of Wick—Final Design

80° F dew point with that previously obtained for the 90-day test (Figure 4-14), it can be seen that the loss in area will require an increase of airflow from 53 cfm to 58. 3 cfm.

6. 2. 3 Control Functions

The basic controls for the AEU blower, air heater, tank heater, and operational status were discussed in the design and layout section. These control functions are rather conventional. However, the urine feed control is unique and will be discussed in more detail.

The new urine feed rate control is a major improvement over the 90-day test design. For the 90-day design, the urine was batch-fed at a pumping rate of 250 mliter/min for 4 minutes each hour. This method provided a 1, 000 mliter/hr or 16. 7 mliter/min average feed rate. However, as previously stated, bench tests revealed that this method did not achieve uniform distribution in the wick package. A new method was devised in which the pumping rate is increased and the feed duration is decreased. This method provides higher pressure in the manifold and better distribution.

After evaluation and testing, a pumping rate of 450 mliter/min was selected for good manifold distribution. To achieve the design feed rate of 3.22 lb/hr or 24.4 mliter/min, a urine feed pump on-time between 3 and 6 seconds was selected with a ratio of 0.0573 pump on-time to pump off-time.

The shorter the on-time, the less chance of flooding, and it was estimated that pump times longer than 6 seconds would substantially increase the possibility of flooding.

The feed control allows the pump to pulse at the preset frequency until wick saturation is achieved as determined by the incipient flooding sensor. Activation of the incipient flooding sensor inhibits the feed pumps until the excess liquid evaporates from the wick. As the wick becomes loaded and can accept less liquid before flooding, the number of feed pulses within a preset time internal decreases. The minimum process rate timer is set for a 30-minute period. If less than 10 pulses occur before the 30-minute timer resets, as determined by a stepping relay in the control logic, the feed control illuminates the process rate low indicator and places the AEU in the standby mode. The activation of this portion of the control indicates that the wick process rate has lowered to 8.13 mliter/min. The wick should be changed, since at this lower rate the AEU cannot process the design requirement of pretreated urine in less than 24 hours.

6.2.4 Component Selection and Drawing Preparation

The major components were selected during the detailed design phase and sufficient detailed drawings were prepared to permit fabrication and assembly of the AEU. A list of the drawings prepared for the AEU appears in Table 6-4.

Components selected for use in the AEU were evaluated to ensure that they were compatible with the design requirements. Such factors as performance, power consumption, reliability, size, weight, volume, and noise level were considered in making the final component selections.

The blower which was selected has sufficient capacity to provide flows in excess of 85 cfm. This excess capacity will permit operation of the AEU at higher feed rates than the 3.22 lb/hr design rate. Flow control is provided by a damper at the blower discharge. This flexibility of the design will permit a thorough parametric evaluation of the air evaporation process.

Table 6-4

AIR EVAPORATION UNIT DRAWING LIST

Drawing No.	Title
1T44332	Air Evaporation/Distillation Unit
1T44546	Mechanical Schematic
1T44547	Electrical Schematic
1T44548	Frame Assembly
1T44549	Wick Package
1T44550	Heater Package
1T44551	Charcoal Filter
1T44552	Lower Transition
1T44553	Blower Transition
1T44554	Control Panel
1T44555	Eliminator and Sump Transition
1T44556	Flow Tube to Blower Connection
1T44557	Storage Tank Assembly

The materials selected for the AEU were based on results of the material evaluation test conducted for the EPU. All ducting was coated internally with Teflon, and most components in contact with the airstream were either Inconel or a corrosion-resistant plastic such as polypropylene. Due to manufacturing and fabrication limitations, the condensate sump and heater fins were constructed of stainless steel. The condenser is alodined aluminum: it was selected as the best unit available within budget limitations. On the basis of limited testing, either anodized or alodined treated aluminum appears to be satisfactory for this application. It was originally intended to obtain a special blower with Teflon coating on all surfaces exposed to the airstream. However, the blower was provided by the vendor with a corrosion-resistant finish, and it was decided to evaluate this blower initially without the expense of Teflon coating. After the functional checkout, these components will be inspected for possible corrosion.

6.2.5 Fabrication and Assembly

Major components of the AEU were fabricated to a schedule designed to permit a logical assembly sequence. The frame, ducting, wick package, and control panels were fabricated and major components mounted to ensure a correct fit. Particular attention was directed to the wick/duct mating flanges. The components were then removed and parts requiring surface protection were painted or Teflon-coated. All components were then permanently assembled and the electrical wiring of the unit completed.

6.2.6 Envelope Dimensions and Weight

The envelope dimensions of the AEU are 51 in. wide by 44 in. high by 19 in. deep (Figure 6-9). This envelope contains all components of the unit, including the water storage tank which would be mounted remote from the unit in a flight system. However, due to the physical limitations of the wick and carbon filter, removal of the water storage tank would not reduce the size of this envelope.

The dry weight of the completed unit is 395 lb. Approximately 10 percent of this weight is accounted for by the water storage tank. Due to the use of commercial components and the selection of material thicknesses for ease of fabrication, it is estimated that the unit weight is approximately 120 percent of that obtainable for a flight unit.

6.2.7 Interface Requirements

The electrical and mechanical interface requirements of the AEU are shown in Table 6-5. Direct current is required for most relays and the counters. The feed pumps, heaters, timers, and other controls operate on 120 vac. The blower operates on 208 vac, three-phase, 400 Hz power. An EPU/AEU interconnecting signal is provided to signal a low level in the EPU storage tank to the AEU.

The majority of the instrumentation is inside the AEU. The only instrumentation interface required is for the relative humidity sensors. These sensors provide a resistance signal which varies with humidity and can be read with a conductivity/resistance bridge and a calibration curve.

Table 6-5

AEU INTERFACE REQUIREMENTS

Electrical

Relay and counter power

28 vdc

5 amp maximum

Air heater bank No. 1 power

120 v, 60 Hz single-phase ac

20 amp maximum

Air heater bank No. 2, feed pumps, and timer control power

120 v, 60 Hz single-phase ac

20 amp maximum

Water tank heater power

120 v, 60 Hz single-phase ac

20 amp maximum

Blower power

208 v, 400 Hz three-phase ac

5 amp maximum

Signal to AEU from EPU (indicates low level in pretreated urine storage tank)

Switch closure indicates low level. Contacts rated for 5 amp at 120 vac

0 to 120 vac 60 Hz supplied to illuminate low level indicator in the air evaporator. Voltage indicates low level

Instrumentation

Humidity indicator at wick outlet

1,000 to 100,000,000 ohms resistance

Humidity indicator at condenser outlet

1,000 to 100,000,000 ohms resistance

Table 6-5

AEU INTERFACE REQUIREMENTS (Continued)

Mechanical
Pretreated urine inlet to unit
Female quick-disconnect
Condensate water from unit
Tube fitting, 3/8-in. OD
Coolant supply to unit
Tube fitting, 3/4-in. OD
Coolant return return from unit
Tube fitting, 3/4-in. OD

Mechanical interfaces are selected to minimize the possibility of improper connection.

Section 7

OPERATIONAL VERIFICATION TESTING

The completed Electrovap was operated to prove its functional capability. The EPU and AEU were first tested with distilled water and all normal system functions and operating modes were demonstrated. Real urine mixed with flush water was then used as a feed to the EPU, the pretreated EPU product solution fed to the AEU, and a five-day integrated system test run. The setup and results of the five-day test are discussed in the following text.

Although the test results presented in this section look very promising, the data represent only short-term system operation under one set of conditions. Additional parametric test data are required to more fully characterize the Electrovap system.

7.1 TEST SETUP

The operational verification tests were conducted in the Space Vehicle Simulator located in Building 31 at MDAC's facility in Huntington Beach, California. Figure 7-1 shows the EPU and AEU in place during the test. The test bed was equipped with chilled coolant supply and return, 208-vac, 400-Hz power, 115 vac, 60-Hz power, 28-vdc power, a nitrogen-purged vent exhausting to the building exterior, and a thermal control system to maintain a constant ambient temperature. Chemical and microbial analysis laboratories are located in the building, allowing rapid checks to be made of system performance.

7.2 TEST PROCEDURE

Urine for the five-day performance verification test was collected daily, stored at 40°F overnight, and diluted with distilled water simulating flush water before being added to the EPU each morning. To allow for chemical and microbial samples, the maximum possible batch size was fed to the EPU

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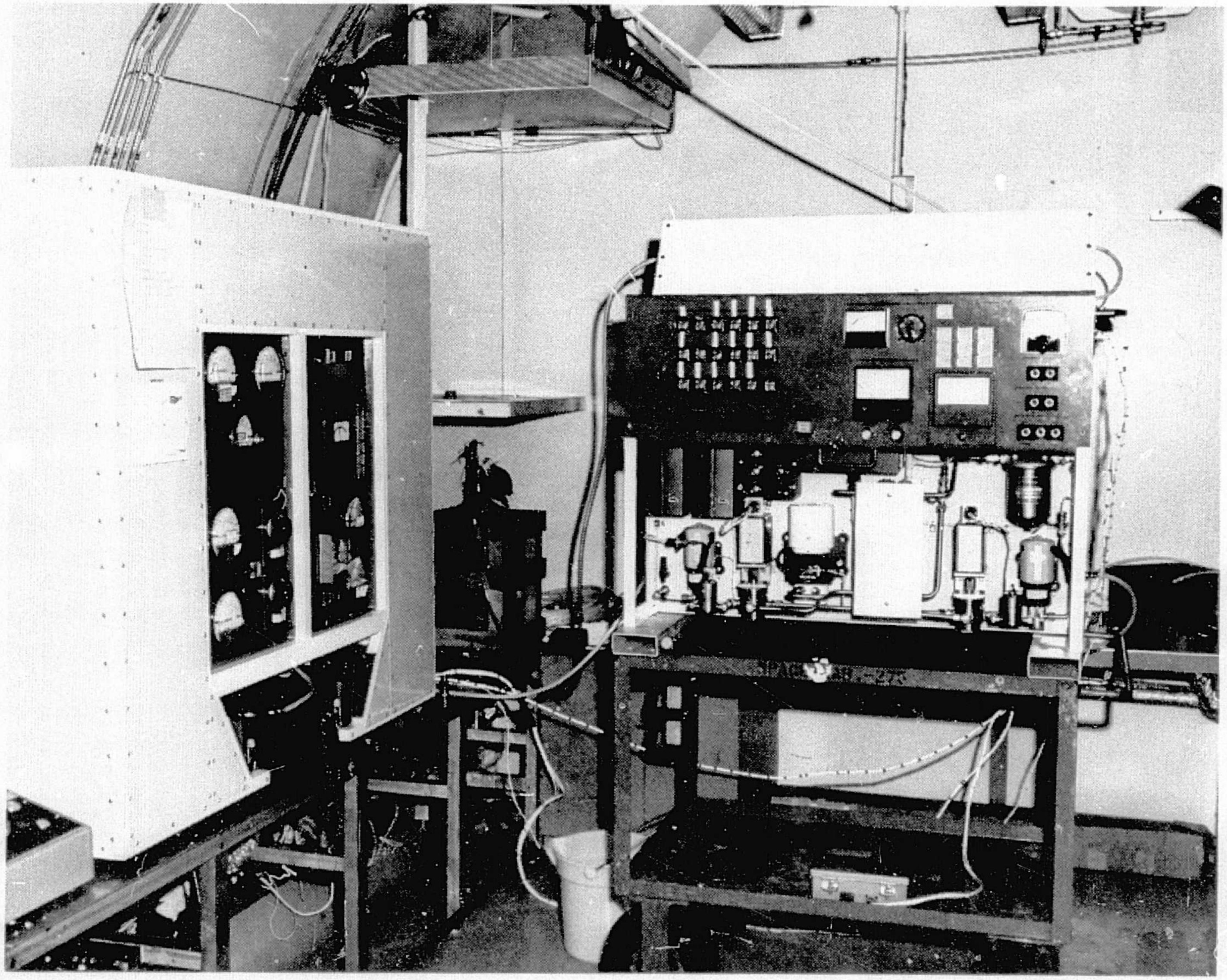

Figure 7-1. Electrolytic Pretreatment and Air Evaporation Units in Space Vehicle Simulator During Operational Verification Tests

for each day's testing. This corresponded to a total batch of 28 lb, composed of 22.4 lb of urine and 5.6 lb of flush water. Approximately 0.2 mliter of an anti-foaming agent per liter of urine was added to the EPU feed to prevent foam blockage of the vent line.

The urine and flush water mixture was then electrolyzed to a TOC level of approximately 1,000 ppm and transferred to the EPU pretreated urine storage tank for feeding to the AEU. This normally occured approximately nine hours after EPU start-up. AEU start-up was inhibited overnight so that manual data recording could be performed on both units. In normal space mission operation, the AEU would be allowed to begin processing automatically whenever the pretreated urine tank received a pretreated batch.

Performance data listed in Table 7-1 were recorded at approximately two-hour intervals during the operation of the units. EPU cell current data, electrolysate TOC concentration, and electrolysate gas oxygen content were recorded at more frequent intervals.

Microbial and chemical analyses of the system performance were performed on samples taken of the system fluids on the schedule shown in Table 7-2. Table 7-2 also lists the types of analyses performed on each sample taken. The method used to perform each analysis is shown in Table 7-3.

Analysis of the electrolysate gas, other than the on-line polarographic oxygen sensor readings, was not performed during the performance verification test. Extensive data are presented in Reference 2 which characterize the electrolysate gas produced in an identical cell under similar operating conditions. No basis exists for indicating that the EPU electrolysate gas composition should differ significantly from that previously reported.

Sound-level measurements were scheduled to record individual EPU and AEU normal operating noise levels, as well as to record the combined noise level for simultaneous operation of both units. Scheduled test conditions for the five-day operational verification test are shown in Table 7-4.

Table 7-1

PERFORMANCE DATA TAKEN DURING THE FIVE-DAY ELECTROVAP OPERATIONAL VERIFICATION TEST

Item	Readout
Electrolytic Pretreatment Unit	
Processing time	Elapsed time recorder
Tank temperatures (3 tanks)	Pyrometer
Oxygen sensor sample temperature	Pyrometer
Oxygen content of electrolysate gas	Polarographic oxygen analyzer
Tank fluid level (3 tanks)	Level indicator
Time remaining on timer	Timer indicator
Cell current	Ammeter*
Alternating current energy input	Watt-hr meter*
Unit status	Relay indicator lights
Air Evaporation Unit	
Operating mode	Status display lights
Processing time	Elapsed time recorder
Potable water produced	Collection cycle counter
Wick inlet temperature	Pyrometer
Wick outlet temperature	Pyrometer
Condenser gas inlet temperature	Pyrometer
Condenser gas outlet temperature	Pyrometer
Heater inlet temperature	Pyrometer
Potable water storage tank temperture	Pyrometer
Condenser coolant supply temperature	Pyrometer
Condenser coolant return temperature	Pyrometer
Blower motor case temperature	Pyrometer
Wick outlet relative humidity	Humidity sensor*
Condenser outlet relative humidity	Humidity sensor*
Appropriate storage tank level	Indicator lights
Pretreated urine quantity fed to wick	Pump cycle counter
Flow tube inlet pressure	Pressure gage
Flow tube differential pressure	Pressure gage
Blower inlet pressure	Pressure gage
Blower outlet pressure	Pressure gage
Wick inlet pressure	Pressure gage
Wick outlet pressure	Pressure gage
Charcoal outlet pressure	Pressure gage
Blower power	Watt meters*
60-Hz energy supplied to unit	Watt-hr meters*
Coolant flow rate to condenser	Turbine flow meter*

*Denotes instrumentation external to the EPU and AEU. All other instrumentation listed is mounted on the units.

Table 7-2

MICROBIAL AND CHEMICAL ANALYSIS SCHEDULE*

Sample Description, Location, and Time to be Taken	Day 1	Day 2	Day 3	Day 4	Day 5	Day 5
Electrolytic Pre-treatment Unit						
Feed-urine storage tank 0800 hr	1, 2	1, 2	1, 2	1, 2	1, 2	Not available - EPU test complete
Processing batch-electrolysate tank 1600 hr	1, 3	1, 3	1, 3	1, 3	1, 3	Not available - EPU test complete
Pretreated urine - pretreated urine storage tank 0800 hr	Not available - EPU batch not yet complete	1, 2	1, 2	1, 2	1, 2	1, 2 (to be taken at 1700 hr)
Air Evaporation Unit						
Product water-product water storage tank ** 1400 hr	Not available - EPU batch not yet complete	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5 (to be taken at 2000 hr)

*Numbers in Table denote analyses to be performed as follows:

1. Microbial analysis - standard 48-hr plate count.
2. Chemical analysis - TOC, TDS, pH, NH_3, and conductivity.
3. Chemical analysis - same as 2, plus urea.
4. Chemical analysis - turbidity, color, odor, foaming.
5. Inorganic analysis - Al, Cr, Ni, Fe, Cl^-, Na, K.

**Microbial samples taken from condenser sump.

Table 7-3

MICROBIAL AND CHEMICAL METHODS OF ANALYSIS

Item	Method of Analysis
Microbial analysis	Millipore field monitor bioassay or standard 48-hr plate counts from serial dilutions of samples taken from septums (see text)
Total organic carbon (ppm)	Beckman Model 915 total organic analyzer
Specific conductivity (μ mho/cm)	YSl Model 31 conductivity bridge with Beckman conductivity cell CBL-Gl K-1.00
pH	Beckman expanded scale pH meter
Ammonia (ppm)	Coleman Model 6A junior spectrophotometer
Turbidity (ppm SiO_2)	Delta Scientific Model 260 water analyzer
Color (Pt-Co units)	Visual comparison of sample and color standards made with potassium chloroplatinate and cobaltous chloride
Foaming	A 100-mliter sample shaken for 30 sec by hand in a 250-mliter stopped glass cylinder and noting heights of the foam remaining after 15 sec
Odor	Subjective evaluation
Total dissolved solids (ppm)	Evaporate 100 mliter of sample in a dry and tared dish, dry to constant weight at 180°C, cool in a desiccator, and weigh
Urea (ppm)	Coleman Model A junior spectrophotometer
Al Cr Ni Fe Na K Cl^-	Perkin-Elmer Model 290 atomic adsorption spectrophotometer

Table 7-4

SCHEDULED PERFORMANCE VERIFICATION TEST OPERATING CONDITIONS

Electrolytic Pretreatment Unit	
Input electrolytic cell voltage	28 vdc
Timer setting	3 hr
Low O_2 setpoint	5 percent O_2
High O_2 setpoint	25 percent O_2
Urine storage tank temperature	118°F
Pretreated urine storage tank temperature	ambient
Batch size	28 lb (80 percent urine, 20 percent distilled water)
Air Evaporation Unit	
Wick inlet temperature	200°F
Wick inlet dewpoint	80°F maximum
Air flow rate	58 cfm
Feed pump cycle timer	5 sec on, 80 sec off
Feed pump instantaneous flow rate	453 mliter/min
Feed pump average flow rate	3.73 lb/hr

A particulate filter with a 30-μ pore size was placed in the fluid line connecting the EPU with the AEU. This filter was to be examined at the conclusion of the test to determine if material from the EPU pretreated urine storage tank was likely to cause plugging of the small 0.013-in.-diameter holes in the AEU wick distribution manifold.

The ullage volume of the EPU urine and flush water in the storage tank was heated to 118°F in an attempt to control gross microbiological growth. Externally powered heaters were not used on the electrolysate or pretreated urine storage tanks. Microbiological samples of the EPU fluids were taken from septums installed in the tank walls, and chemical samples taken from the sample valves provided.

The AEU microbiological samples were taken from a septum installed in the condenser sump. AEU product wat r samples were taken from the product water storage tank sample valve. The product water storage tank heater was not turned on during the test to allow the true chemical composition of the product water to be analyzed.

7.3 TEST RESULTS

The five-day operational verification test was conducted August 13-17, 1973. Electrovap performance data taken during the test are summarized in Table 7-5. Both the EPU and AEU performed at or above design levels throughout the test, and only minor problems were encountered with the performance of either unit.

A total of 135.6 lb was processed by the EPU and 93.9 lb of product water were produced by the AEU. The 41.7-lb differential in the amount fed to the EPU and the product water produced included:

A. 11.8 lb which filled the EPU pretreated urine storage tank ullage volume, filters, and plumbing lines during the processing of the initial batch.

B. 18.8 lb taken for microbial and chemical analysis (3.75 lb/day).

C. 6.2 lb of H_2, O_2, N_2, CO_2, and other gases (except water vapor). vented from the system.

D. 2.3 lb of solids retained in the EPU filters and in the AEU wick.

E. 2.6 lb due to water vapor lost through the system vent and other losses.

Although the wick was not dried down before or after the test, some of the 2.6 lb listed in Item E could be accounted for by the wick being more fully saturated at the end of the test than at the beginning.

The polarographic oxygen sensor on the EPU was monitored closely through four days of testing to assess the ability of the sensor to provide a reliable indication of the TOC level of the electrolysate. The data collected are shown in Figure 7-2. The low readings observed on the first test day are a result of the larger-than-normal batch being processed due to the initially empty ullage volume in the electrolysate tank. Near the end of processing the first batch, the oxygen sensor did not return to its previous level after a calibration check and was thought to require recharging. The sensor had been charged approximately 60 days before the test. After recharging, the sensor appeared to exhibit normal behavior.

Table 7-5

ELECTROVAP PERFORMANCE DATA SUMMARY

Electrolytic Pretreatment Unit	
Total weight of urine and flush water processed (lb)	135.6
Total processing time (hr)	46.95
Average TOC of EPU feed (ppm)	5,187
Average TOC of EPU product (ppm)	778
Average processing rate (lb/hr)	2.89
Energy consumption	
Electrolysis cell energy (w-hr)	33,080
Other electrical energy (w-hr)	14,000*
	47,080*
Specific energy requirement (w-hr/lb of urine and flush water processed*)	348
Air Evaporation Unit	
Total weight of product water	93.89
Total processing time (hr)	23.46
Average TOC content of pretreated urine feed (ppm)	778
Average TOC content of product water (ppm)	10.42
Average conductivity of pretreated urine feed (μ mho/cm)	14,280
Average conductivity of product water (μ mho/cm)	12.9
Average TDS of pretreated urine feed (ppm)	12,531
Average TDS of product water (ppm)	<1
Average processing rate (lb/hr)	3.99
Energy balance	
Energy input	
DC energy (w-hr)	3,284
60-Hz ac energy (w-hr)	59,000
400-Hz ac energy (w-hr)	4,809
Total	67,093
Energy rejection	
Condenser coolant	48,500
Cabin atmosphere	18,593
Total	67,093
Specific input energy requirement (w-hr/lb of product water)	715

*Includes energy required to heat the urine storage tank to an average temperature of 105°F during the five days of testing.

On Day 3, the sensor indicated a higher-than-normal reading about one hour after batch processing was begun. On checking the lines to the sensor, water condensation was found to be blocking passage of the sample gas. The lines were drained and normal operation resumed. The liquid was again noticed in the sample lines on Day 4 and loops of plastic tubing were added at the

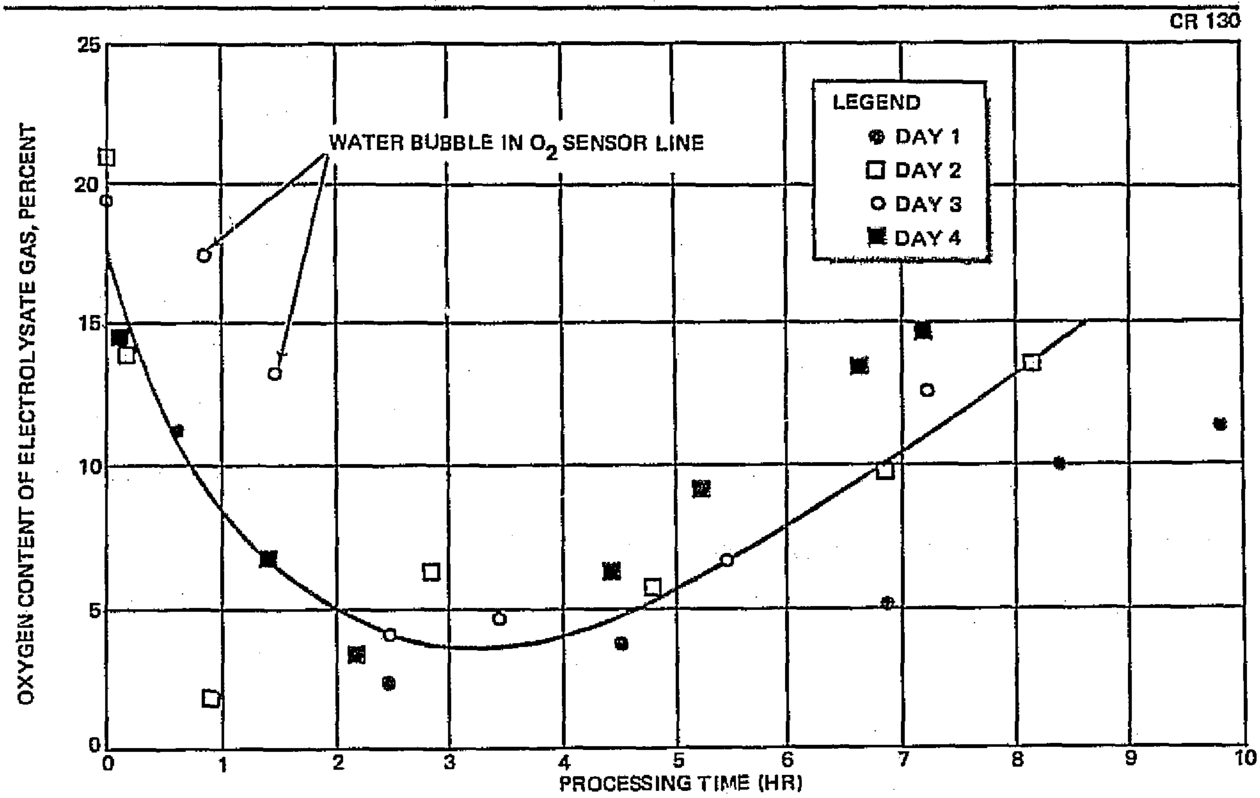

Figure 7-2. Oxygen Content of Electrolysate Gas as a Function of Processing Time

inlet and outlet sample line connection to the main vent line to prevent condensate blockage. The tubing loops appeared to substantially reduce the likelihood of sample line blockage.

Posttest analysis indicated that future condensation problems can be eliminated (in a 1-g environment) by reorienting the sample loop heat exchanger (which allows the sample to cool to ambient temperature before passage to the sensor) to allow liquid condensed to drain back into the electrolysate tank.

At the start of processing each batch of urine during five-day test, the low oxygen point was set at 5 percent and the high point at 25 percent. As the oxygen content in the electrolysate gas began to rise, TOC samples were run to determine the repeatability of the oxygen sensor to terminate batch processing. The results are shown in Table 7-6. Although there is some variation in the data obtained, oxygen readings above approximately 15 percent seemed to be a workable indicator that the TOC content of the batch was less than 1, 000 ppm. On verification of the acceptability of the TOC content,

Table 7-6

TOC REDUCTION RELATED TO PROCESSING TIME AND OXYGEN SENSOR READING

Initial TOC Concentration (ppm)	Final TOC Concentration (ppm)	Total Processing Time (hr)	Final Oxygen Sensor Reading (percent)	Initial Batch Size (lb)
6,272	1,225	10.41	13.1	31.2
5,330	935	10.51	19.2	28.0
4,795	689	8.77	17.5	28.0
4,660	480	8.20	17.7	28.0
4,880	562	10.06	Not Taken	28.0

the high set point was moved to the oxygen percentage indicated in Table 7-6, and batch processing was thereby terminated automatically.

During the processing of the fifth batch in the EPU, the low level float switch light came on. This would normally indicate an empty electrolysate tank and terminate processing. A fuse in the float switch circuit was removed to allow the complete batch to be processed, and the float switch was removed and examined. The examination revealed that the electrolysate leaked into the switch due to an inadequately tightened fluid pipe fitting. The leak alone should not have caused failure of the potted switch, but the insulation on both wires was found to be defective, causing an electrical short. The failed switch was replaced with a spare unit that was properly torqued into the fluid fitting.

AEU performance during the five-day test was compared with predicted performance and good correlation was obtained. This comparison is shown in Figure 7-3. The predicted performance was calculated from the performance

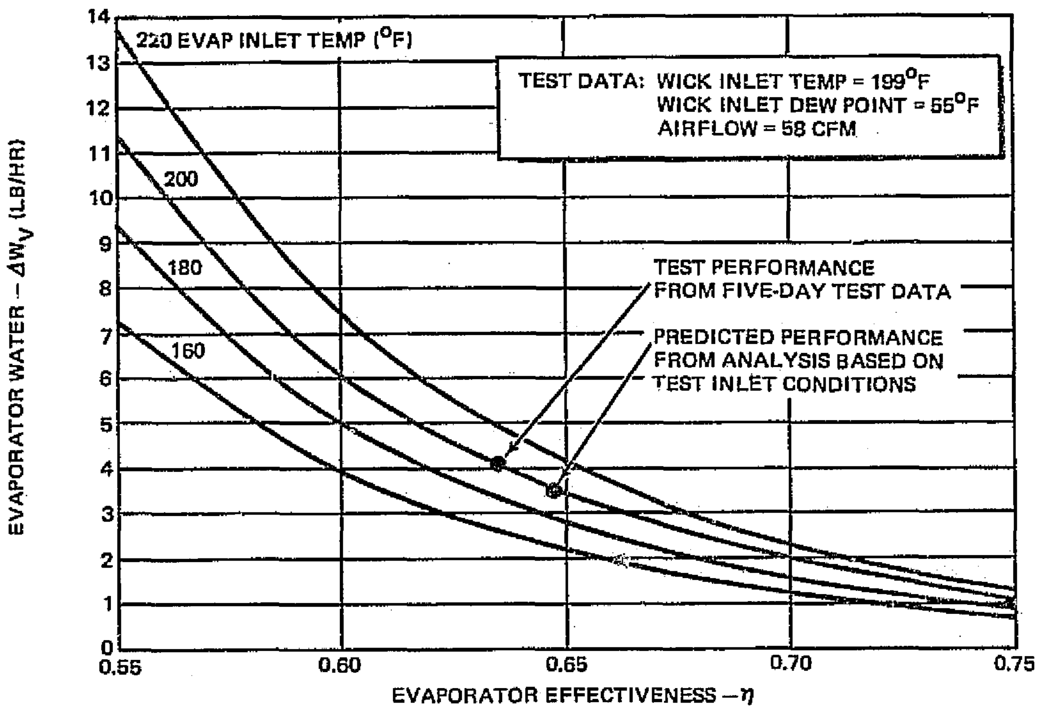

Figure 7-3. Comparison of Test Performance of the Air Evaporation Unit Wick with Predicted Performance

of similar wicks over their useful lives. As wick performance degrades as the amount of solids loading in the wick increases, the deviation of the test performance data point is in the expected direction with respect to the predicted performance point.

No evidence of wick flooding was experienced during normal operation in the five-day test. Coolant flow to the condenser was turned off briefly on Day 4 to precipitate wick flooding, and correct operation of the incipient flooding sensor was verified.

The AEU condensate drain cycles did not correlate well with the volumes measured on draining the product water storage tank. As this is a gravity drain system with only about 5 in. of water head, it was determined that the 1/4-in.-OD drain line was emptying the condenser sump slowly enough (about 30 sec) to allow the condensate entering the sump during draining to be a significant fraction of the total volume drained. This problem will be eliminated by increasing the drain line size from 1/4-in. OD to 3/8-in. OD.

Temperature, pressure, and relative humidity data recorded during the test are shown in Table 7-7. High, low, and average values are indicated for each reading. On initiation of processing the first batch of urine and flush water, the electrolysate temperature rose to the high value recorded, 190°F. The insulation blanket on this tank was subsequently removed, preventing the batch maximum temperatures from exceeding 178°F.

Two methods of microbial analysis were used to evaluate the Electrovap system performance: (1) Millipore field monitor bioassay and (2) standard 48-hr plate count bioassay using Trypticase soy agar. The Millipore field monitor analysis was originally slated for use on all samples. However, problems in passing the samples through the field monitor filter material during the first two days led to the discontinuance of this method. It was believed that the field monitors were being clogged by the solids content in the urine, electrolysate, and pretreated urine samples. The field monitor sample technique could have been employed throughout the test on the AEU product water samples, but to standardize the sample collection procedure, sampling at this point was also done using the 48-hr plate count technique on Days 3, 4, and 5. Microbial analysis results are presented in Table 7-8.

Although microbial contamination was found in the product water while processing batches 1 and 2, no contamination was observed in batches 3 and 4. No initial system sterilization was performed, nor was any attempt made to sterilize the system between batches. Batch 5 was not sampled for microbial contamination.

Physical and chemical analyses of the EPU urine and flush water feed solution are shown in Table 7-9. Analysis of the electrolysate during processing is shown in Table 7-10, the analysis of the pretreated urine fed to the AEU in Table 7-11, and the AEU product water analysis in Table 7-12.

As shown in Table 7-12, the quality of the product water improved during the test. The first batch processed exceeded the NAS-NRC standards for spacecraft potable water in only three areas—pH, NH_3, and foaming. The final batch processed met all except the pH standard. A small ion exchange resin bed could easily be added to the AEU output to allow this standard to be met.

Table 7-7

TEMPERATURE, PRESSURE, AIR FLOW, AND RELATIVE HUMIDITY DATA

	Number of Data Points	High	Low	Average
Electrolytic Pretreatment Unit				
Urine storage tank temperature (°F)	32	128	73	105
Electrolysate tank temperature (°F)	32	190	74	154
Pretreated urine storage tank temperature (°F)	32	127	73	95
Electrolysate gas sample temperature (°F)	31	85	74	80
Air Evaporation Unit				
Wick inlet temperature (°F)	15	203	197	199
Wick outlet temperature (°F)	15	128	100	107
Condenser gas inlet temperature (°F)	15	106	98	101
Condenser gas outlet temperature (°F)	15	69	48	56
Heater inlet temperature (°F)	15	85	65	72
Product water storage tank temperature (°F)	15	82	64	71
Condenser coolant supply temperature (°F)	15	57	37	44
Condenser coolant return temperature (°F)	15	78	61	66
Blower motor case temperature (°F)	15	188	104	108
Flow tube inlet pressure (in. H_2O)	12	-6.4	-5.8	-6.2
Flow tube differential pressure (in. H_2O)	12	2.5	2.3	2.4
Blower inlet pressure (in. H_2O)	11	-7.6	-7.0	-7.3
Blower outlet pressure (in. H_2O)	13	8.7	8.2	8.3
Wick inlet pressure (in. H_2O)	13	0.6	0.4	0.5
Wick outlet pressure (in. H_2O)	13	-4.0	-3.3	-3.8
Charcoal outlet pressure (in. H_2O)	13	-5.5	-4.6	-5.0
Air flow rate (ft^3/min)	12	60	55	58
Wick outlet relative humidity (percent)	11	68	46	57
Condenser outlet relative (percent)	11	98	93	96

Table 7-8

MICROBIAL ANALYSIS DATA

Number of Viable Organisms per 1.0 mliter

Sample	Day 1	Day 2	Day 3	Day 4	Day 5
EPU urine storage tank	TNTC*	TNTC*	1.4×10^{7}**	2.9×10^{6}**	4.6×10^{8}**
EPU electrolysate tank (during batch processing)	Equivocal*	Equivocal*	0**	0**	0**
EPU pretreated urine storage tank	Sample not taken	Equivocal*	Equivocal*	0**	0**
AEU product water condenser sump	Product water not yet produced	TNTC*	2.0×10^{1}*	0**	0**

Sample results denoted as equivocal had a slimy residue present on the filter material. Determination of colony growth on these samples was uncertain.

*Denotes results based on Millipore field monitor bioassay.

**Denotes results based on plate count bioassay using Trypticase soy agar.

TNTC denotes organisms too numerous to count.

Table 7-9

EPU URINE STORAGE TANK FLUID CHEMICAL AND PHYSICAL ANALYSIS

Item	Day 1	2	3	4	5
Total dissolved solids (ppm)	18, 622	18, 618	16, 622	15, 602	15, 060
Total organic carbon (ppm)	6, 272	5, 330	4, 795	4, 660	4, 880
pH	6. 25	6. 15	6. 20	6. 10	7. 15
NH_3 (ppm)	93. 6	89. 7	25. 5	107. 0	75. 0
Conductivity (μ mho/cm)	15, 300	16, 400	15, 300	14, 200	18, 500
Urea (ppm)	--	16, 540	6, 850	7, 730	13, 140

Table 7-10

EPU ELECTROLYSATE TANK FLUID CHEMICAL AND PHYSICAL ANALYSIS

Item	Day 1	2	3	4	5
Processing time prior to taking sample (hr)	2. 8	5. 5	5. 5	5. 1	6. 2
Total dissolved solids (ppm)	17, 169	14, 080	12, 856	12, 076	12, 016
Total organic carbon (ppm)	5, 212	2, 462	1, 400	1, 512	1, 827
pH	6. 35	5. 90	4. 40	4. 60	5. 30
Conductivity (μ mho/cm)	16, 700	19, 300	16, 200	15, 800	18, 100

Table 7-11

EPU PRETREATED URINE TANK FLUID CHEMICAL AND PHYSICAL ANALYSIS

Item	Day 1	2	3	4	5
Total dissolved solids (ppm)	12, 300	12, 968	12, 974	11, 986	12, 425
Total organic carbon (ppm)	1, 225	935	689	480	562
pH	2.75	3.60	4.70	3.70	3.80
NH_3 (ppm)	6.1	6.1	6.1	12.2	6.1
Conductivity (μ mho/cm)	14, 800	15, 200	14, 400	14, 200	12, 800
Urea (ppm)	270	90.0	23.5	68.5	32.1

Tables 7-9 and 7-10 show that the average TDS content of the EPU feed was 16, 905 ppm and the electrolytic process reduced this to an average of 12, 531 ppm. Thus, a 26-percent reduction was obtained in the amount of solids to be handled by the wick.

Analysis of the 30 μ filter installed in the pretreated urine line revealed that approximately 5 mliter of brownish residue had been collected in the filter housing and on the filter surface. The material had a creamy texture and appeared likely to clog the wick distribution manifold should the filter not be in place.

Results of the sound level measurements taken during normal Electrovap operation are presented in Figure 7-4. The combined noise level of the EPU and AEU as measured 2 feet in front of each unit (the units were at right angles to each other, as shown in Figure 7-1) in the reverberant Space Vehicle Simulator was less than the acoustic spectra criteria of NCA-60. The overall dBA reading with both units operating was 63. The overall reading with the AEU alone operating was also measured as 63 dBA and with the EPU alone operating, the overall level was 54 dBA. With both units operating, the noise level goal set for the EPU alone was very nearly met, with only the AEU blow high-frequency noise being significantly above the design goal.

Table 7-12

AEU PRODUCT WATER CHEMICAL AND PHYSICAL ANALYSIS

	NAS-NRC Standard*	Batch 1	2	3	4	5
Total dissolved solids (ppm)	1,000	<1	<1	<1	<1	<1
Total organic carbon (ppm)	NS	6.1	10.0	13.6	6.0	16.4
pH	7.0-8.0	6.8	6.8	6.30	6.10	6.20
NH_3 (ppm)	1, pH > 7 10, pH < 7	1.56	3.48	0.57	0.60	0.69
Conductivity (μmho/cm)	NS	9.9	14.1	16.3	11.7	12.5
Turbidity (Jackson units)	< 5	2	2	2	0	2
Color (Pt-Co units)	<15	<5	<5	<5	<5	<5
Odor (none)	unobjectionable	none	none	none	none	none
Foaming (amount persistent)	none after 5 sec	trace	trace	trace	trace	none
Al (ppm)	NS	-	<0.02	-	-	<0.02
Ni (ppm)	0.1	-	<0.04	-	-	<0.04
Cr (ppm)	0.1	-	<0.03	-	-	<0.03
Fe (ppm)	1.0	-	<0.05	-	-	<0.05
Na (ppm)	NS	-	<0.02	-	-	<0.02
K (ppm)	NS	-	<0.05	-	-	<0.05
Cl^- (ppm)	250	-	0.02	-	-	0.025

*For six-month mission duration

NS = no standard established

\- = no analysis made

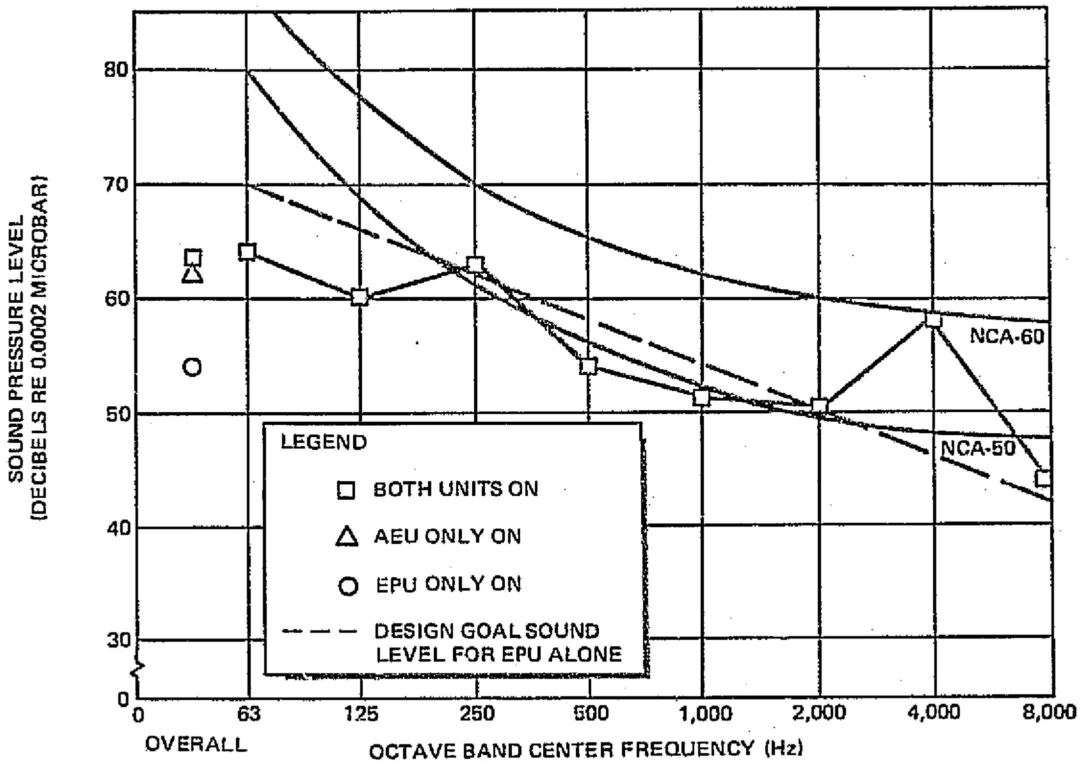

Figure 7-4. Acoustic Spectra

Section 8
PERFORMANCE EVALUATION PLANS

The operational verification test described in the previous section allowed only a limited amount of Electrovap performance data to be collected due to its brief duration. So that the Electrovap performance may be more fully characterized, a comprehensive parametric test program plan was prepared. This plan is structured to combine the EPU with the AEU, and the test program will investigate the beneficial aspects of electrolytic pretreatment of urine for subsequent processing by distillation. The test will generate data applicable to all distillation processes using electrolytically pretreated urine. The test program outline is given in Appendix B: it includes a description of the technical approach and a statement of work for such a program.

A document was also prepared to review the applicability of a combined electrolytic pretreatment/reverse osmosis system. This document is presented in Appendix C. It outlines a plan for a comprehensive evaluation of the advantages of such a system.

Section 9
CONCLUSIONS AND RECOMMENDATIONS

The results of the five-day test of the Electrovap system verified the feasibility of this concept for the recovery of potable water from human urine, while meeting the National Academy of Sciences - National Research Council standards. The integrated Electrovap system, which consisted of the EPU and AEU, successfully completed the verification test with only minor malfunctions. Liquid condensation in the EPU vent caused blockage in the oxygen sensor line, and a float switch in the EPU electrolysate tank failed on the final day of the test. The vent line was modified slightly and the float switch bypassed to complete the test. The AEU condensate drain line proved to be undersized, and the low condensate flow rate from the metering sump contributed to some inaccuracy in the recording obtained from the automatic condensate totalizer. However, an accurate total was obtained manually by draining and measuring the quantity of water collected in the storage tank. Minor system modifications which will eliminate these problems are presented in Section 7.3 of this report.

Additional modifications will be incorporated in the two units to improve system operation as a result of the pretest checkouts and the five-day test. During pretest checkout of the EPU, it was determined that the timer reset switch required additional contacts. The proposed modification was checked and verified by a breadboard test and a new switch ordered. The new switch was not received in time for the five-day test. However, this reset feature is provided for abnormal operation only and was not required for the test. Additionally, it was determined that the EPU operation could be improved by replacing the present three-hour timer with a 12-hour timer. The additional time interval would improve reliability since the three-hour interval is a minimum and a six- to eight-hour interval would be more desirable. A new 12-hour timer has been ordered and will be installed.

During the pretest checkout of the AEU, problems were experienced with the wick feed minimum process rate timer. The timer did not always reset after expiration of the preset 30-minute interval. After adjustments of the internal switches and clutch, the timer did not cause problems during the five-day test. However, an improved timer and control circuit are presently being investigated and will be installed if this new design proves more reliable.

Based on the results of this study and the five-day test, the following recommendations are made for future efforts:

A. Extensive testing of the Electrovap system should be conducted. This will generate parametric data common to the use of electrolytic pretreatment for all distillation systems. A plan for the extended test is given in Appendix B.

B. Design requirements should be prepared for the integration of electrolytic pretreatment with a reverse osmosis water reclamation unit. A plan to define these requirements is given in Appendix C.

C. A study should be conducted to evaluate the utilization of the waste heat generated in the EPU electrolysate tank to improve the performance of other components of the water recovery system. For example, this heat could be utilized in the AEU to reduce the power penalty required to heat the air entering the wick.

D. A study should be conducted to evaluate methods to utilize the gases generated by the electrolytic pretreatment of urine. These gases are presently vented to the atmosphere and lost. In a space vehicle, these gases could either be vented overboard or collected, separated, and reused. A plan for study to evaluate techniques for the collection, separation, and reuse of these gases is described in Reference 9.

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Appendix A

CONTRACT STUDY SUBTASK 4.2

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS WORKSHEETS

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FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Air Evaporation Unit (Page 1 of 4)

Part No. and Description	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Main't. Req'd to Rep. (Estimated Time)	Accep. Opr'n Limits (Method of Fault Detection	Effect on Water Quality	Recommendations (Type Redundancy)
Urine feed pump March Mod-210-10	Transfer and meter pretreated urine to wick	<u>Leakage - external</u>	Chemical attack	Unable to maintain design process rate	Unpleasant odor in cabin; contaminate atmos. (3)	Replace pump (0. 5 hr)	No external leakage (visual and smell)	None	(Spare pump)
		<u>Cavitation or clogging</u>	Precipitate formation in pump		None (4)		Maintain design feed rate (feed totalizer)		
		<u>Motor failure</u>	Elect/mech failure		None (4)		Maintain design feed rate (feed totalizer)		
Blower Dynamic Air Mod/C100J-3	To move air and water vapor thru wick evap	<u>Leakage - external</u>	Seal damaged due to chem. attack	Degradation in performance due to lower airflow	Unpleasant odor in cabin; contaminate atmos. (3)	Replace seals or blower (1 hr)	No external leakage (smell)	None	(Repair kit or spare blower)
		<u>Bearing failure</u>	Mechanical failure		None (4)	Replace blower (1 hr)	Maintain design airflow (ΔP light)		(Spare blower)
		<u>Motor failure</u>	Elect/mech failure		None (4)				(Spare blower)
		<u>Impeller failure</u>	Chemical attack		None (4)				(Spare blower)
Wick : T44549-1	Separation of water from urine	<u>Leakage - external</u>	Chemical attack	Unable to maintain design process rate	Unpleasant odor in cabon; contaminate atmos. (3)	Replace wick (0. 5 hr)	No external leakage (visual and smell)		(Spare wick)
		<u>Flooding</u>	Excessive feed rate or expended wick	Degradation of water quality due to contam. entrainment	None (4)	Check feed control and wick. Replace def. component (0. 5 hr)	No flooding (flooding ind. and feed totalizer)	May not pass chemical std.	(Spare control and wick)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Air Evaporation Unit (Page 2 of 4)

Part No. and Description	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Main't. Req'd to Rep. (Estimated Time)	Accep. Opr'n Limits (Method of Fault Detection)	Effect on Water Quality	Recommendations (Type Redundancy)
Wick (Cont)		Feed tube clogging	Precipitate formation in in feed tube	Unable to maintain design process rate	None (4)	Replace wick (0. 5 hr)	Maintain design feed rate (feed totalizer)	None	(Spare wick)
Carbon bed 1T44551-1	To remove atmos. contaminants	Leakage - external	Seal damaged due to chemical attack	Loss of water vapor	Unpleasant odor in cabin; contaminate atmos. (3)	Replace seals (1 hr)	No external leakage (smell)	None	(Repair kit)
		Clogging	Particulate in airstream	Degradation in performance due to lower airflow	None (4)	Replace carbon (1 hr)	Maintain design airflow (ΔP light)	None	(Spare carbon)
		Channeling	Air passages in carbon bed	Degradation of water quality due to contaminants	None (4)		Removal of contaminants (contaminant monitoring and bed ΔP)	May not pass chemical std.	(Spare carbon)
Air filter (Part of carbon bed)	To remove solid particulates from airstream	Clogging	Excessive particulate matter	Degradation in performance due to lower airflow	None (4)	Replace filter (0. 5 hr)	Maintain design flow (ΔP light and filter ΔP)	None	(Spare filter)
Condenser Janitrol 47D20	To condense water vapor in airstream	Leakage - external	Seal damage due to chem. attack or condenser corrosion	Loss of water vapor	Unpleasant odor in cabin; contaminate atmos. (3)	Repair seals or replace condenser (2 hr)	No external leakage (smell)	None	(Repair kit or spare condenser)
		Leakage - internal	Corrosion	Degradation of water quality	None (4)	Replace condenser (2 hr)	Potability standards (contaminant monitoring for coolanol in water	May not meet chemical std	(Spare cond.)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Air Evaporation Unit (Page 3 of 4)

Part No. and Description	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Main't. Req'd to Rep. (Estimated Time)	Accep. Opr'n Limits (Method of Fault Detection)	Effect on Water Quality	Recommen-dations (Type Redundancy)
Condenser (Cont)		Coolanol leakage - external	Corrosion or mechanical failure	Loss of coolant	None (4)	Repair leak or replace condenser (2 hr)	No external leakage (visual)	None	(Repair kit or spare cond)
		Clogging	Excessive particulate matter	Degradation in performance due to lower airflow	None (4)	Replace condenser and filter (2. 5 hr)	Maintain design flow (ΔP light and cond. ΔP)	None	(Spare cond and filter)
Air heater Watlow G8A54	To maintain design temp at wick inlet	Fails open	Electrical failure due to corrosion	Degradation in performance due to lower temp.	None (4)	Replace heater (1 hr)	Maintain design temp. (temperature indicator)	None	(Spare heater)
		Leakage - external	Seal damaged due to chemical attack	Loss of atmos. and reduced airflow	Unpleasant odor in cabin; contaminate atmos. (3)	Replace seals (1 hr)	No external leakage (smell)	None	(Repair kit)
Air heater controller Love Mod 72-1	Control air heater temp.	Fails on	Elect/mech failure	Possible loss of air heater	None (4)	Replace thermostat (0. 5 hr)	Maintain design air temperature (temp. ind.)	None	(Spare thermostat)
		Fails off		Degradation in performance due to low temp					
Condensate float switch Gems 01702	Meter condensate flow rate by actuating water totalizer	Fails high	Mechanical failure	Overflow of condenser sump	None (4)	Replace switch (0. 5 hr)	Actuate condensate valve (condensate water totalizer)	None	(Spare switch)
		Fails low		Loss of water measurement	None (5)		Close cond. valve (cond. water totalizer)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Air Evaporation Unit (Page 4 of 4)

Part No. and Description	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Main't. Req'd to Rep. (Estimated Time)	Accep. Opr'n Limits (Method of Fault Detection)	Effect on Water Quality	Recommendations (Type Redundancy)
Condensate valve Skinner V52HA2022	Drains condensate sump	Fails closed	Elect/mech failure	Overflow of cond. sump	None (4)	Replace valve (0.5 hr)	Open on high float signal (cond. water totalizer)	None	(Spare valve)
		Fails open		Loss of water measurement	None (5)		Close on low float signal (cond. water totalizer)		
Tank heater Montgomery Bros 5A433W001	Maintain microbial control in water	Fails open	Electrical failure	Loss of microbial control	None (4)	Replace heater (1 hr)	Maintain design water temp. (temp. indicator)	May not meet microbial standard	(Spare heater)
Tank heater thermostat Fenwal 28-230806-304	Control tank heater temp.	Fails on	Elect/mech failure	Possible loss of water heater	None (4)	Replace therm. (0.5 hr)	Maintain design water temp. (temp. ind.)	None	(Spare thermostat)
		Fails off		Loss of microbial control				May not meet microbial standard	
Tank float switch Gem LS1975	Override urine feed control	Fails high	Mechanical failure	Overflow of tank	None (4)	Replace switch (0.5 hr)	Turn off feed pump (visual)	None	(Spare switch)
		Fails low		Cannot maintain process rate			Turn on feed pump (feed totalizer and visual)		
Feed pump control Master Electronic Controls RCO-115A-15/360	Controls feed pump "on" cycle and actuates feed totalizer	Fails on	Elect/mech failure	Flooding of wick	None (4)	Replace control (0.5 hr)	Maintain design feed rate (feed totalizer)	May not pass chemical standard	(Spare control)
		Fails off		Unable to maintain design process rate				None	

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 1 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
P1-Urine Pump	To transfer urine from urine tank to electrolysate loop	Lack of gear rotation (motor runs)							
Micropump 12-40-316-757		(1) Gear breakage	Fatigue	Unable to process additional batches. Could hang up in urine transfer stage.	None (4)	Replace pump (1 hr)	Ability of pump to transfer urine. (Low level in electrolysate tank and high level in urine tank displayed on indicator panel.)	None	Replace pump with spare and rebuild failed pump for use as spare (spare pump)
		(2) Gear wear	Abrasion						
		(3) Gear jammed	(1) Galling						
			(2) Foreign material						
			(3) Chemical attack						
			(4) Thermal expansion						
		(4) Shaft breakage	Fatigue						
		(5) Shaft seizure	(1) Galling						
			(2) Foreign material						
		(6) Gear seizure	Bearing wear						
		(7) Jammed or slipping driven magnet	(1) Foreign material						
			(2) Chemical attack of coupling O-ring						
			(3) Age degradation of coupling O-ring						
		(8) Hub breakage	(1) Fatigue						
			(2) Chemical attack						
		(9) Slipping drive magnet	Loose set screws (vibration)						

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 2 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
P1-Urine Pump (Continued)		External leakage							
		(1) Front seal leakage	(1) Chemical attack	Unable to process full batch and possible damage to other components from urine leakage.	Objectionable odor in cabin (3)	Replace seal (0.5 hr)	No external leakage (visual observation)	None	Conduct material tests to verify seal mat'l. (spare seal)
			(2) Loose cover plate screws			Tighten screws (0.1 hr)			Use thread locking compound on screws. (spare screws)
		(2) Rear cup leakage	Chemical attack			Replace pump (1 hr)			Replace pump with spare – rebuild failed pump for use as spare (spare pump)
		(3) Rear cup O-ring leakage	(1) Chemical attack						
			(2) Loose rear cup attachment screws						
		Internal leakage							
		(1) Gear wear	Abrasion	Possible inability to process full batch	None (4)	Replace pump (1 hr)	Ability of pump to transfer urine. (Low level in electrolysate tank and high level in urine tank are displayed on indicator panel.)	None	Replace pump with spare — rebuild failed pump for use as spare (spare pump)
		(2) Front seal wear	Abrasion						
		(3) Leakage at relief ball	(1) Surface imperfections and erosion						
			(2) Cold flow distortion						
		(4) Relief ball jammed (open)	Gall						
		(5) Relief spring breakage	Fatigue						
		(6) Reliev screw change setting	Vibration						

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 3 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
P1-Urine Pump (Continued)		No motor rotation							
		(1) Jammed drive magnet	Foreign matl on magnet	Unable to process additional batches. System hangs up in transfer stage.	None (4)	Replace pump (1 hr)	Ability of pump to transfer urine. (Low level in electrolysate tank and high level in urine tank are displayed on indicator panel.	None	Replace pump with spare and rebuild failed pump for use as spare (spare pump)
		(2) Motor bearing seizure	(1) Wear (2) Foreign material						
		(3) Commutator continuity lost	Wear						
		(4) Brush continuity lost	Wear						
		(5) Brush spring breakage	Fatigue						
		(6) Brush spring relaxation	High temperature						
		(7) Field winding continuity	(1) Over temperature (2) Foreign material						
		(8) Lead wire break (open)	(1) Fatigue						
		(9) Lead wire short	(2) Fatigue	Also blown fuse indicated.			(Also blown fuse indicated.)		

NOTES:

(1) Wear between the teflon gears and the polypropylene seal may be the life limiting element of the pump. The clearance between the gears and seal, and between the gears and body establish the internal leakage and hence the efficiency of the pump.

(2) The teflon gears are wear-life limited. The vendor stated that the pump life is estimated at 1500 hours continuous duty at 9 psid bypass valve setting — increased Δp will reduce life of pump.

(3) Magnet material is beryllium ferrite.

(4) All attachment screws should be secured to insure against vibration induced torque relaxation. (Micropump will assemble with Loctite if specified.)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 4 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
P3-Water Pump Micropump 12-40-316-757	To transfer electrolysate to water tank at end of electrolysis cycle.	<u>Lack of gear rotation (motor runs)</u> Same as for urine pump (P1)	Same as for urine pump (P1)	Unable to process additional batches — system hangs up in product transfer stage.	None (4)	Replace pump (1 hr)	Ability of pump to transfer product. (High level in electrolysate tank and low level in product tank are displayed on indicator panel.)	None	Replace pump with spare and rebuild failed pump for use as spare (spare pump)
		<u>External leakage</u> (1) Front seal leakage	(1) Chemical attack	Unable to transfer full batch and possible damage to other components from urine leakage.	Objectionable odor in cabin (3)	Replace seal (0.5 hr)	No external leakage (visual observation)	None	Conduct material tests to verify seal material. (spare seal)
			(2) Loose cover plate screws			Tighten screws (0.1 hr)			Use thread locking compound on screws (spare screws)
		(2) Rear cup leakage	(1) Chemical attack			Replace pump (1 hr)			Replace pump with spare — rebuild failed pump for use as spare (spare pump)
		(3) Rear cup O-ring leakage	(1) Chemical attack						
			(2) Loose rear cup attachment screws						
		<u>Internal leakage</u> Same as for urine pump (P1)	Same as for urine pump (P1)	Possible inability to transfer full batch. Could hang up in product transfer stage.	None (4)	Replace pump (1 hr)	Ability of pump to transfer product. (High level in electrolysate tank and low level in product tank are displayed on indicator panel.)	None	Replace pump with spare—rebuild failed pump for use as spare (spare pump)
		<u>No motor rotation</u> Same as for urine pump (P1)	Same as for urine pump (P1)	Unable to process additional batches. System hangs up in product transfer stage.		Replace pump (1 hr)	Ability of pump to transfer product. (High level in electrolysate tank and low level in product tank are displayed on indicator panel.)	None	Replace pump with spare and rebuild failed pump for use as spare (spare pump)

Same notes apply as for urine pump.

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 5 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
P2 Circulation Pump Fluoro-carbon Co. SP4000	Circulate electrolysate through electrolysis cell	Lack of pump rotation							
		(1) Disk seizure	(1) Foreign material	Loss of function	None (4)	Remove pump and replace with spare (4 hr)	Ability of pump to displace gas in cell with liquid which results in steady current flow to cell. (Unit may hang up in process mode.)	None—O_2 sensor prevents transfer of unprocessed batch	Replace pump with spare and rebuild failed pump for use as spare (spare pump)
			(2) Precipitates						
		(2) Drive rod seizure	(1) Gall						
			(2) Wear						
		(3) Slipping drive disk	Loose set screw						
		(4) Motor failure	Various—see list for P1 motor.						
		(See P1 for various types of motor failures)							
		Lack of pump output							
		(1) Broken disk	Wear						
		(2) Clogged inlet	Foreign material						
		(3) Clogged outlet	Foreign material						
		(4) Loss of prime	Gas in loops						
		External leakage							
		(1) Front to rear chamber loose	Loose attachment screws	Unable to process full batch—possible damage to other components from leakage.	Objectionable odor in cabin (3)	Tighten screws (0.5 hr)	No external leakage (visual inspection)	None	(Tool kit)
		(2) Seal bellows cracked	Fatigue			Remove pump and replace with spare (4 hr)			(Spare pump)
		(3) Rod to disk connection loose	Vibration						(Spare pump)
		(4) Seal plate to rear chamber leak	Loose attach screws			Tighten screws (0.5 hr)			(Tool kit)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 6 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Opra Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
SV2-Motor Act. Valve Conant 2316-3/8 wi/ 80 wp	Admit batch to electrolysis loop, direct flow in electrolysis loop.	External leak (1) Lower seal leak	(1) Chemical attack (2) Wear	Unable to process full batch—possible damage to other components from leakage	Objectionable odor in cabin (3)	Drain electrolysis loop, replace seal (3 hr)	No ext leakage (visual inspe 'ion)	None	(Spare seal)
		(2) Upper seal leak	(1) Chemical attack (2) Wear						
		Internal leak (in circulate position) Sleeve leak	(1) Wear (2) Spring failure or loss of tension	None (SV4 closed)	None (4)	Drain electrolysis loop, replace sleeve. (3 hr)	No internal leakage SV4 provides redundancy. (Checks on product quality)	None—SV4 provides redundancy	(Spare sleeve)
		Seize in transfer position Rotor seize	(1) Gall (2) Foreign material	Unable to process additional batches	None (4)	Drain electrolysis loop, clean and polish valve. (4 hr)	Correct positioning of valve. (Limit switches in operator prohibit transfer of circulation until valve is in correct position. SV4 closed until P1 runs)	None	(Tool kit)
		Seize in circulate position	(1) Gall (2) Foreign material						
		Seize in mid-travel	(1) Gall (2) Foreign material						
		Blockage in transfer pos'n	Foreign material	Unable to process additional batches. Could hang up in urine transfer stage.		Drain electrolysis loop, disassemble and remove blockage (3 hr)	No blockage. (Low level in electrolysate tank illuminates operational indicator light.)		
		Blockage in circulate pos'n	(1) Foreign material (2) Precipitates	Unable to process batch			No blockage—(unit hangs up in process mode)	None—O_2 sensor prevents transfer of unprocessed batch.	

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 7 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
SV1-Motor Act. Valve Conant 2316-3/8 wi/ 80 wp	Admit batch to water storage tank, direct flow in electrolysis loop	External leak (See SV2 for mode breakdown)	(See SV2 for cause breakdowns)	Unable to process full batch—possible damage to other components from leakage	Objectionable odor in cabin (3)	Drain electrolysis loop, replace seal (3 hr)	No ext leakage (visual inspection)	None	(Spare seal)
		Internal leak (in circulate position)		None (SV3 closed)	None (4)	Drain electrolysis loop, replace sleeve (3 hr)	No internal leakage, SV3 provides redundancy. (Checks on product quality)	None—SV3 redundant valve.	(Spare sleeve)
		Seize in transfer position		Unable to process additional batches		Drain electrolysis loop, clean and polish valve. (4 hr)	Correct positioning of valve. (Limit switches in operator prohibit transfer or circulation until valve is in correct position. SV4 closed until P1 runs)	None	(Tool kit)
		Seize in circulate position				Drain electrolysis loop, clean and polish valve (4 hr)			
		Seize in mid-travel						None—interlock limit switches prevent additional operation. O_2 sensor prevents transfer of unprocessed batch.	
		Blockage in transfer position		Unable to process additional batches. Could hang up in product transfer stage.		Drain electrolysis loop, disassemble and remove blockage. (3 hr)	No blockage—(unit hangs in transfer mode)	None	
		Blockage in circulate position		Unable to process batch			No blockage—(unit hangs in process mode)	None—O_2 sensor prevents transfer of unprocessed batch.	

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 8 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
MV2-Drain/Sample Valve Whitey-1GS6-316	Control flow for draining or sampling urine tank	External leak	Chemical attack of seal	Unable to process full batches — possible damage to other components from leakage.	Objectionable odor in cabin (3)	Replace valve (2.5 hr)	No ext. leakage (visual inspection)	None	(Spare valve)
		Flow blockage	Foreign material	Unable to sample input urine.	None (4)	Remove valve, clean, replace (2.5 hr)	No flow blockage (visual monitoring of sample flow rate)		Filter urine through coarse mesh screen. (Tool kit)
MV3-Urine Valve Whitey-43F4-316	Isolate urine tank.	External leak	Chemical attack of seal	Unable to process full batches. Possible damage to other components from leakage.	Objectionable odor in cabin (3)	Replace valve (3 hr)	No ext. leakage (visual inspection)	None	(Spare valve)
		Flow blockage	Foreign material	Unable to process additional batches could hang up in urine transfer stage.	None (4)	Remove valve, clean, replace (3 hr)	No flow blockage. (Tank levels displayed on panel)		(Tool kit)
		Seize open	Foreign material	None		Replace valve (3 hr)	No flow blockage (Attempt to turn valve)		(Spare valve)
MV4-Drain/Sample Valve Whitey-1GS6-X-316	Control flow for draining or sampling electrolysate tank.	External leak	Chemical attack of seal	Unable to process full batches. Possible damage to other components from leakage.	Objectionable odor in cabin (3)	Replace valve (3 hr)	No ext. leakage (visual inspection)	None	(Spare valve)
		Flow blockage	Foreign material	Unable to sample electrolysate.	None (4)	Remove valve, clean, replace. (3 hr)	No flow blockage. (Visual monitoring of sample flow rate.)		(Tool kit)
MV5-Drain/Sample Valve Whitey-1GS6-316	Control flow for draining or sampling storage tank.	External leak	Chemical attack of seal	Unable to process full batches. Possible damage to other components from leakage.	Objectionable odor in cabin (3)	Replace valve (3 hr)	No ext. leakage (visual inspection)	None	(Spare valve)
		Flow blockage	Foreign material	Unable to sample water storage	None (4)	Remove valve, clean, replace. (3 hr)	No flow blockage (visual monitoring of sample flow rate)		(Tool kit)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 9 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
MV6-Water Valve Whitey 43F4-316	Isolate water storage tank	<u>External leak</u>	Chemical attack of seal	Unable to process full batches—possible damage to other components from leakage.	Objectionable odor in cabin (3)	Replace valve (3 hr)	No ext leakage (visible inspection)	None	(Spare valve)
		<u>Flow blockage</u>	Foreign material	Wick evap.not fed, runs dry.	None (4)	Remove valve clean, replace (3 hr)	No flow blockage (high level in product tank shuts off normal system operation and displays indicator)		(Tool kit)
		<u>Seize open</u>	Foreign material	None		Replace valve (3 hr)	No flow blockage (attempt to turn valve)		(Spare valve)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 10 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
SV5-Solenoid Valve Skinner V51HA2150	Prevent overfill of urine tank	Fail closed (clog same)	Foreign material	Unable to process additional batches	Must use back-up urine collection system (4)	Replace valve (1 hr)	Open and close on command. (Flow of urine from collection unit. Low level in urine tank illuminates display.)	None	(Spare valve)
		Fail open (int.leak same)	Foreign material	Possible overfill of urine tank and spillage from tank vent.	None (4)		Open and close on command. (High level in urine tank illuminates fault display.)		
		External Leak	Chemical attack of seal	Unable to process full batches. Possible damage to other components from leakage.	Objectionable odor in cabin (4)		No ext leakage (visual inspection)		
SV4-Solenoid Valve Skinner V52HA2022	Blocks flow in event of SV2 failure	Fail closed (clog same)	Foreign material	Unable to process additional batches. Could hang up in product transfer stage.	None (4)	Replace valve (3 hr)	Open and close on command. (High level in urine tank illuminates display.)	None	(Spare valve)
		Fail open (int.leak same)	Foreign material	None			Open and close on command. (None—redundant valve)		
		External Leak	Chemical attack of seal	Unable to process full batches, possible damage to other components from leakage.	Objectionable odor in cabin (3)		No ext leakage (visual inspection)		
SV3-Solenoid Valve Skinner V52HA2022	Blocks flow in event of SV1 failure	Fail closed (clog same)	Foreign material	Unable to process additional batches	None (4)	Replace valve (3 hr)	Open and close on command	None	(Spare valve)
		Fail open (int.leak same)	Foreign material	None			Open and close on command. (None—redundant valve)		
		External Leak	Chemical attack of seal	Unable to process full batches, possible damage to other components from leakage.	Objectionable odor in cabin (3)		No ext leakage (visual inspection)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 11 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
RV1 Relief Valve Circle Seal D520T1-2M-4	To prevent urine storage tank overpressurization in the event of heater control failure and vent blockage.	External leak (failure to close same) Failure to open is not considered a credible failure mode and requires a prior failure of two other components.	Chemical attack of O-ring	None	Objectionable odor in cabin. Venting of hazardous gases to cabin in electrolysate gas recirculation mode. (3)	Replace relief valve (0.5 hr)	No ext. leakage (crew sense odor)	None	(Spare relief valve)
RV2 Relief Valve Circle Seal D520T1-2M-4	To prevent electrolysate tank overpressurization in the event of vent blockage.	External leak (failure to close same) Failure to open is not considered a credible failure mode and requires a prior component failure.	Chemical attack of O-ring	None	Objectionable odor and venting of hazardous gases to cabin. (3)	Replace relief valve (0.5 hr)	No ext. leakage (crew sense odor)	None	(Spare relief valve)
RV3 Relief Valve Circle Seal D520T1-2M-4	To prevent pretreated water storage tank overpressurization in the event of heater control failure and vent blockage.	External leak (failure to close same) Failure to open is not considered a credible failure mode and requires a prior failure of two other components	Chemical attack of O-ring	None	Objectionable odor in cabin. (3)	Replace relief valve (0.5 hr)	No ext. leakage (crew sense odor)	None	(Spare relief valve)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 12 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accep Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Electrolytic Cell 1T44422-1 1T44422-501	Electrolyze urine	<u>External leak</u>	Chemical attack of materials	Unable to process full batch. Possible damage to other components from leakage.	Objectionable odor in cabin. Venting of hazardous gases to cabin. (3)	Remove cell and repair (16 hr)	No external leakage (Visual inspection and crew detection of odor in cabin)	None	(Spare gaskets and other cell components)
		<u>Flow blockage</u>	Precipitates or foreign material	Unable to circulate electrolysate	None (4)	Remove cell, disassemble, clean (16 hr)	No blockage (Unit hangs in process mode)	None— O_2 sensor prevents transfer of unprocessed batch	(Spare gaskets and other cell components)
		<u>Electrical open</u>	Chemical attack	Unable to process batch.	None (4)	Remove cell, restore electrical continuity, replace electrodes if required. (24 hr)	20-28 volts provides 15-40 amps current (Unit hangs up in process mode)		
		<u>Electrical short</u>	Foreign material	Unable to process batch	None (4)	Remove cell, disassemble, clean, reinstall. (16 hr)	15-40 amps current (Tripped circuit breaker, unit hangs up in process mode)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 13 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Filter Filterite LMO4S-1/2B (50μ)	To remove particulate matter from product	Clog	Inadequate service frequency	Unable to process additional batches. Could hang-up in product transfer stage.	None (4)	Remove, clean, replace element (2 hr)	Less than 20 psi ΔP (Product transfer cycle time greater than 10 min.)	None	(Spare element)
		Element fail (Internal leak)	Fatigue	Product becomes contaminated with particulate matter.	None (4)	Remove filter, clean, replace element, drain and flush product tank (4 hr)	Removal of most particles smaller than 30μ. (Clogging of air evap flow)	Excessive particulate content.	(Spare element)
		External leak	(1) Chemical attack of seal	Unable to output full batches.	Objectionable odor in cabin. (3)	(1) Replace seal	No ext. leakage (visual inspection)	None	(Spare seal)
			(2) Vibration of clamp bolt	Possible damage to other components from leakage.		(2) Tighten clamp			(Tool kit)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 14 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Urine storage tank 1T44406-1	Hold urine before processing	External leak	Chemical attack (thru hole in teflon)	Unable to process full batch and possible damage to other components from urine leakage	Objectionable odor in cabin - possible discharge of hazardous gases to cabin. (3)	Drain tank and apply silicon rubber over leak (36 hr)	No ext. leakage (visual inspection - low level in urine tank shuts off normal system operation, crew detects odor in cabin)	None	Visually inspect teflon tank coating for defects before use. (Spare silicon rubber)
		Inlet fitting plugged	Particulate contamination in urine.	Unable to process additional batches	Possible urine overflow at collection unit. (3)	Disassemble line and remove blockage (3 hr)	No blockage - (visual observation of urine back-up at collection unit)		Filter incoming urine thru coarse mesh (Tool kit)
		Outlet fitting plugged	Particulate contamination in urine.	Unable to process additional batches could hang up in urine transfer stage.	None (4)	Drain tank, disassemble line and remove blockage (3 hr)	No blockage - (low level in electrolysate tank and high level in urine tank indicated by display lights)		Filter incoming urine thru coarse mesh. (Tool kit)
Electrolysate tank 1T44[illegible]-1	Hold urine during processing	External leak	Chemical attack (thru hole in teflon)	Unable to process full batch and possible damage to other components from electrolysate leakage.	Objectionable odor and possible discharge of hazardous gases to cabin. (3)	Drain tank and apply silicon rubber over leak (36 hr)	No ext. leakage (visual inspection, crew detects odor in cabin)	None	Visually inspect teflon tank coating for defects before use. (Spare silicon rubber)
		Inlet fitting plugged	Particulate contamination or precipitated compounds.	(1) Unable to transfer next batch of urine to electrolysate loop. (2) Unable to circulate electrolysate for processing - no circulation in electrolysis cell. (3) Circulation pump runs dead headed. (Pump is not damaged by dead headed operation.)	None (4)	Disassemble line and remove blockage (2 hr)	No blockage - (low level in electrolysate tank and high level in urine tank indicated by display lights.	None - O_2 sensor does not permit unprocessed batch to be transferred.	(Tool kit)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 15 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Electrolysate tank (Cont)		<u>Outlet fitting plugged</u>	Particulate contamination or precipitated compounds.	(1) Unable to transfer batch of electrolysate to water storage tank	None (4)	Drain tank disassemble line and remove blockage. (3 hrs)	No blockage (low level in water storage tank and high level in electrolysate tank indicated by display lights.)	None - O_2 sensor does not permit unprocessed batch to be transferred.	(Tool kit)
				(2) Unable to circulate electrolysate for processing - no circulation in electrolysis cell.					
				(3) Circulation pump runs starved. (Does not damage pump)		Drain tank, disassemble line and remove blockage (3 hrs)	No blockage	None - O_2 sensor does not permit unprocessed batch to be transferred.	
Pretreated water storage tank 1T44406-1	Hold pretreated water for transfer to wick evap.	<u>Inlet fitting plugged</u>	Precipitate from electrolysis loop.	Unable to transfer electrolysate to storage tank. Unable to process additional batches. Could hang-up in product transfer stage.	None (4)	Disassemble line and remove blockage (3 hr)	No blockage - (high level in electrolysate tank illuminates indicator light.)	None	(Tool kit)
		<u>Outlet fitting plugged</u>	Precipitate from electrolysis loop.	Unable to transfer water to air evap. Unable to pretreat additional batches. Wick evap may operate with no input water.		Drain tank, disassemble line and remove blockage (3 hr)	No blockage - (high level in water tank illuminates indicator and shuts off normal system operation.		
		<u>External leak</u>	Chemical attack (thru hole in teflon)	Unable to process full batch and possible damage to other components from leakage.	Objectionable odor in cabin. (3)	Drain tank and apply silicon rubber over leak (36 hr)	No ext. leakage (visual inspection, low level in tank indicated by display lights, crew detects odor in cabin)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 16 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
O_2 sensor Beckman Mod 100800	Sense O_2 content of gas in electrolysate tank	Fail indicating O_2 below lo set point, between lo and hi set point, or above hi set point.	Sensor malfunction or amplifier malfunction	Hangs up in process mode. Timer provides minimum quality batch in event of hi failure just after accurate lo indication.	None (4)	Replace sensor (2 hr) or replace amplifier (4 hr)	Oxygen content indicated ±2 percent (overly long process time in batch - visual inspection by crew.)	None	(Spare sensor and spare amplifier)
		Off calibration	Amplifier drift	Inaccurate batch end point or hang up in process mode. Timer provides minimum quality batch.	None (4)	Recalibrate in cabin atmos. (0.5 hr)	Oxygen content indicated ±2 percent (periodic cabin air calibrations, interval is TBD)	None	Establish calib. interval in system testing (provide calib. instructions)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 17 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Urine tank heater controller Fenwal Mod 53605-2	To control power to urine tank heater	Fail on	Electronics fail	Excessive temp in urine tank. Possibility of some urine boiloff	None (4)	Replace controller (2 hr)	Control temp to 165 ±5° F in urine tank. (Periodic monitoring of tank temps. by crew)	None	(Spare controller)
		Fail off	(1) Thermistor wiring open	Low temp. in urine tank. Possible micro-organism growth		Drain tank, replace thermistor (3 hr)	Control temp to 165 ±5° F in urine tank. (Periodic monitoring of tank temps. And microorganism count by crew.)		(Spare thermistor)
			(2) Electronics fail			Replace controller (2 hr)			(Spare controller)
		Short	Chaffed insulation	and trip circuit breaker					
Processed water tank heater controller Fenwal Mod 53605-2	To control power to processed water tank heater	Fail on	Electronics fail	Excessive temp. in processed water tank. Possibility of boiloff.	None (4)	Replace controller (2 hr)	Control temp to 165 ±5° F in processed water tank. (Periodic monitoring of tank temps. by crew).	None	(Spare controller)
		Fail off	(1) Thermistor wiring open	Low temp. in processed water tank. Possible micro-organism growth		Drain tank, replace thermistor (3 hr)	Control temp to 165 ±5° F in processed water tank. (Periodic monitoring of tank temps. by crew.)	None. Assuming air evap. is operated above sterilization temp.	(Spare thermistor)
			(2) Electronics fail			Replace controller (2 hr)			(Spare controller)
		Short	Chaffed insulation	also trip circuit breaker					

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (page 18 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Circuit breaker 40 amp capacity Mech Prod 700-001-35	To protect electrolysis cell dc power circuit	Opens for no detectable reason when load is not excessive.	Burned contacts	Shuts system down	None (4)	Replace circuit breaker (0.2 hr)	(Circuit breaker opens at load below rated amperage.)	None	(Stock spare circuit breakers)
			Off calibration on low side.						
		Fails to open for prolonged excessive load.	Off calibration on high side.	Does not shut system down for load above rated amperage		Replace circuit breaker, disassemble and inspect electrolysis cell. Replace if necessary. Inspect circuit for shorts. (2.0 hr)	(Circuit breaker passes an excessive load and does not open.)		
Plug valve operator 80 WP Conant Bros, Inc	Move plug valve to circulate or transfer position	Does not move valve	Bearings or speed reduction gears ruined.	Cannot process batches	None (4)	Replace operator (0.5 hr)	(Remove operator from valve and find that valve is not jammed.)	None	(Stock spare operator)
			Open circuit in windings.				(Test windings for continuity)		
			Shorted or burned out contacts.	Fuse blows and system shuts down.			(Check winding resistance.)		
		Does not move to correct position.	Valve travel limit switch cams are out of adjustment.	Cannot process batches.		Replace operator if moving the valve 180 degrees separately does not solve the problem (0.5 hr)	(Valve does not position for transfer or circulate properly.)		
		Bad limit switches	Valve continues to move, does not stop at any position.			Replace operator (0.5 hr)	(Valve rotates without stopping.)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 19 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Urine and pretreated water tank heaters Montgomery Bros 5A433W001	Maintain microbial control in water.	Fails open	Resistance element Open circuit.	Loss of microbial control.	None (4)	Replace heater (1 hr)	(Check that heater is on and fuse has not blown, and observe temp indicator. Test resistance of heater, approx 9 ohms.)	May not meet microbial std.	(Stock spare heater)
Urine and pretreated water heater thermostat Fenwal 28-230806-304	Control tank heater temp	Fails on	Electrical or mechanical failure	Possible loss of water heater	None (4)	Replace thermostat (0.5 hr)	Observe high, out of range tank temp on temp indicator)	None	(Stock spare thermostat)
		Fails off		Loss of microbial control.			(Observe low temp on temp indicator)	May not meet microbial std.	(Stock spare thermostat)
Tank temp indicator API Mod 7035	Verify tank temperatures as controlled by thermostat	Open or shorted circuit, off calibration	Electrical failure or mechanical failure	Tank temp cannot be verified	None (5)	Replace indicator (0.5 hr)	(Indicator reads full scale or zero scale and does not respond to on or off cycles of thermostat.)	None	(Stock spare indicator)
Tank liquid level indicator Gems Type 24130	Verify tank liquid levels as controlled by float switches.	Open or shorted circuit	Electrical failure	Tank liquid level cannot be verified	None (5)	Replace indicator (0.5 hr)	(Indicator reads full scale or zero scale and does not respond to tank filling and emptying cycles.)	None	(Stock spare indicator)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 20 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Relay 3PDT 1210N-3C-115 vac Guardian	Automatic control	Relay cannot be actuated	Open circuit in coil	Unable to process batch. No signal to a valve or motor	None (4)	Install new plug-in relay. Check circuit. (0.2 h.)	(Determine where batch stalled. Check relay coil for 1100 ohms ±10 percent.)	None	(Stock spare relays)
		Controlled comp. Cannot be actuated.	Burned contacts				(Remove relay cover, inspect.)		
		Relay cannot be actuated	Coil shorted or burned out	Fuse blows, shuts system off			(Observe fuse warning light and blown fuse. Check relay coil for 1100 ohms.)		
Latching relay W103L-CPX-9 Magnecraft 12 vdc	Shut system off for blown fuses. (Controls main power relay)	Relay cannot be actuated	Open circuit in coil	Unable to shut system down	None (4)	Install new plug-in relay, check circuits for open fuses. Press momentary switch to reset latching relay. (0.2 hr)	(A fuse has blown but system stays on. Check relay coil for 1000 ohms)	None	(Stock spare relays)
		No signal to main power relay	Burned contacts	Shuts down system			(No fuse has blown but system shut down.)		
		Relay cannot be actuated	Coil shorted or burned out	Latching relay fuse blows and relay unable to shut system down.			(Check relay coil for 1000 ohms. Check relay fuse.)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 21 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Latching relay W88ALCPX-12 Magnecraft	Prevents reset of timer during power interruptions	Relay cannot be actuated	Open circuit in coil	Timer unable to start or end batch	None (4)	Install new plug-in relay. Check circuit. (0.2 hr)	(Check relay coils for 1100 ohms, ±10 percent.)	None	(Stock spare relays)
		Relay actuated but clock not affected.	Burned contacts	Batch cannot be terminated or batch cannot be started. Clock cannot be reset.			(Remove relay cover, inspect.)		
		Relay cannot be actuated	Coil shorted or burned out	Latching relay fuse blows and relay unable to reset clock. System is off.			(Check relay fuse. Check relay coils for 1100 ohms.)		
Main power relay (actuated by 115 vac) SPST, 50 A contacts W88ADX-2 Magnecraft	Shuts system down for any fuse failure. Also used to simulate shut down during dark part of orbit.	Relay cannot be actuated	Open circuit in coil	System is off.	None (4)	Install new relay (0.5 hr)	(Check all fuses and fuse warning light. Check relay coil for 1100 ohms.)	None	(Stock spare relays)
		Relay actuated but 110 vac power not on in syst.	Burned contacts	System is off			(Inspect relay contacts.)		
		Relay cannot be actuated	Coil shorted or burned out	System is off			(Check fuse of main power relay. Check relay coil for 1100 ohms.)		

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 22 of 24)

Part No, and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Electrolysis cell power relays W88ADX-2 Magnecraft (actuated by 115 vac) SPST, 50 A contacts	Shuts off power to electrolysis	Relays cannot be actuated. (Double failure required before system operation is damaged)	Open circuits in both relay coils.	System unable to process urine, continues running. Unfinished urine batch is dumped into air evap. holding tank if the gaseous oxygen batch quality controller proves unfeasible and is abandoned.	Objectionable odor in cabin (3)	Replace relay when it fails, this will avoid a double failure that would cause system failure. If a double failure occurs replace relays, disassemble and clean air evap system. (0.5 hr)	(Observe relay armature for actuation when electrolysis system is running or check coild for 1100 ohms ±10 percent.)	Severe degradation of water quality	Inspect relays once each week to avoid double failure. (Stock spare relays)
		Relays both actuate but electrolysis dc power not on. (Double failure required before system is damaged)	Burned contacts				(Inspect contacts for damage. These contacts are operating at 1/4 of their continuous duty rating and burning should be infrequent.)		Inspect contacts once each month to avoid double failure. (Stock spare relays)
		One relay cannot be operated.	Coil shorted or burned out.	Fuse blows and shuts down system.	None (4)	Replace relay (0.5 hr)	(Observe fuse warning light and blown fuse. Check relay coil for 1100 ohms.)	None	(Stock spare relays)

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 23 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Opra Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
Batch timer MTD-3H Industrial Timer Corp.	Determines minimum batch duration	Motor will not run Magnetic clutch will not engage	Open circuit, gears or bearings ruined. Open circuit	Electrolytic batch is processed indefinitely. ↓	None (4) ↓	Install new timer (0.5 hr) ↓	(Bench test timer.) ↓	None ↓	(Stock spare timer) ↓
Low level float switches Gems LS 1975	Prevents complete emptying of tank and terminate transfer operations	Fails to sense liquid level ↓	Shorted contacts Burned or open contacts	Transfer to next process is prevented and system shuts down. (Tank is sensed as empty) System can attempt to transfer to next process from an empty tank.	None (4) ↓	Replace float switch (0.5 hr) ↓	(Tank liquid level is not in low range but float switch is on.) (Tank liquid level is below low range or empty and switch does not close.)	None ↓	(Stock spare float switches) ↓
Mid level float switches Gems LS 1975	Indicate that a batch is available for processing or transfer.	Fails to sense liquid level	Shorted contacts. Burned or open contacts	System can transfer and process very small batches System cannot transfer or process a batch	None (4) ↓	Replace float switch (0.5 hr) ↓	(Tank liquid level is below mid range setting but float switch is on.) (Tank liquid level is above mid range and switch does not close.)	None ↓	(Stock spare float switches) ↓

FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

Electrolytic Pretreatment Unit (Page 24 of 24)

Part No. and Desc	Function	Failure Mode	Failure Cause	Effect on System	Effect on Crew (Criticality)	Maint Reqd to Rep (Also Est Time)	Accept Oprn Limits (Method of Fault Det)	Effect on Water Quality	Recommendations (Type Redundancy)
High level float switches Gems LS 1975	Warns that tank is full	Fails to sense liquid level	Shorted contacts	False warning that the tank is full. This prevents further processing of batches. A warning light is turned on.	None (4)	Replace float switch (0.5 hr)	Tank liquid level is not in high range but float switch indicates tank is full. Transfer into tank cannot occur. System shuts down.	None	(Stock spare float switches)
		↓	Burned or open contacts	Fails to warn that tank is full. The urine tank has two high level float switches, either switch can close a solenoid valve and terminate filling. A warning light indicates that one urine tank float switch has failed. Other tanks cannot overfill unless there has been a simultaneous float switch failure in the tank upstream.	↓	↓	Level in tank is in the high range but level switch does not sense this.	↓	↓

Appendix B

CONTRACT STUDY SUBTASK 4.6E

A PROGRAM FOR EVALUATION OF A COMBINED ELECTROLYTIC PRETREATMENT/AIR EVAPORATION SYSTEM FOR SPACECRAFT POTABLE WATER RECLAMATION

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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MDC G4230

A PROGRAM FOR EVALUATION OF A COMBINED ELECTROLYTIC PRETREATMENT/AIR EVAPORATION SYSTEM FOR SPACECRAFT POTABLE WATER RECLAMATION

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For
Johnson Space Center
National Aeronautics and Space Administration

PREFACE

This report describes a parametric test program to investigate the beneficial aspects of electrolytic pretreatment of urine for subsequent processing by distillation. An electrolytic pretreatment unit was constructed for NASA-JSC under Contract No. NAS1-11781 and integrated with an MDAC-furnished air evaporation/distillation unit. The combined system is called the Electrovap. The next logical step in this program is to conduct parametric tests that will more fully characterize the Electrovap system and generate data applicable to all distillation processes using electrolytically pretreated urine. A technical approach and statement of work for such a parametric test program are described.

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FIGURES

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Section 1
INTRODUCTION AND SUMMARY

Future long-duration manned space missions will need potable water to be reclaimed from human wastes to conserve weight and volume.

The development of the electrolytic pretreatment process for urine will help to solve many problems in meeting the exacting chemical and microbial standards for water reclamation in spacecraft. The electrolytic pretreatment method has been successfully demonstrated (Reference 1). It uses electrolysis of urine rather than expendable chemical additives to remove organic materials such as urea from urine prior to final purification. The process eliminates substances that might produce ammonia or other unacceptable organic contaminants in the product water by converting those organic contaminants into recoverable gases such as CO_2, H_2, O_2, and N_2. Additionally, it eliminates microbiological contaminants through the production of excess chlorine.

The end product of the electrolytic pretreatment process is a sterile solution of inorganic salts which can be purified by any of several final treatment methods such as air evaporation, vapor compression, or reverse osmosis.

The benefits of electrolytic pretreatment include the elimination of corrosive chemicals for pretreatment, the production of a stable concentrate that can be stored without the risk of releasing contaminants generally associated with urine residue, and the formation of a solution that can be processed at a higher temperature by the final treatment system. The ability to process urine at higher temperature results in smaller equipment and in microbiological control.

The program presented in this report verifies, by test, the operational advantages of electrolytic pretreatment by the operation of a complete six-man, flight prototype, potable water recovery system. The water recovery system will consist of an electrolytic pretreatment unit (EPU), developed for NASA-JSC under Contract No. NAS 1-11781, coupled with a closed-cycle air evaporation unit (AEU) developed at MDAC expense.

The test program will fully characterize the electrolytic pretreatment process under actual operating conditions through the determination of such EPU parameters as power profiles, flow rates, control system capabilities, by-product gas production, and pretreated urine composition as a function of input energy. The integrated EPU/AEU test program will also provide data applicable to all distillation processes using pretreated urine feed. These data include:

1. Long-term sterility data.
2. Maximum possible operating temperatures in excess of the urea breakdown temperature.
3. Degree of electrolytic pretreatment required for distillation as a function of temperature.
4. Energy and power profiles.
5. The extent to which electrolytically pretreated urine brine can be concentrated (as a function of operating temperature) and still produce an acceptable product water.
6. Long-term corrosion effects of the distillate from electrolytically pretreated urine on the selected EPU and AEU materials of construction.
7. Posttreatment polishing requirements, if any, to meet potability requirements.
8. The degree of improvement in potable water yields as a result of reduced urine solids.
9. Expected improvements in handling and storing electrolytically pretreated urine.

Section 2
TECHNICAL DISCUSSION

2.1 ELECTROLYTIC PRETREATMENT UNIT

The overall electrochemical reaction for the electrolytic urine pretreatment process is approximately represented by the relation (Reference 2):

$$X_3O + 2C_2H_6N_2O_2 + 11\ H_2O \rightarrow X_3O_4 + 17\ H_2 + 2N_2 + 2O_2 + 4CO_2$$

In this equation, X_3O represents the inorganic compounds in raw urine, $C_2H_6N_2O_2$ represents the organic compounds in raw urine, and X_3O_4 represents the inorganic compounds in electrolyzed urine. X represents all atoms other than C, H, N, and O and is considered to have an atomic weight of approximately 30, which is about average for real human urine.

In actual practice, a batch of urine is circulated through an electrolysis cell operating at a current density in the range of 200 to 300 mA/cm^2 until the total organic carbon (TOC), chemical oxygen demand (COD), and total Kjeldahl nitrogen (TKN) are each reduced to the desired level. Figure 1, from Reference 2, indicates the composite transient behavior of these and other parameters during the electrolysis of 4-liter batches of urine. An estimate of the salts remaining after electrolysis is shown in Table 1 (from Reference 2). Essentially all organic material is converted in the process. The organic sulfur is converted to sulfate and most of the organic chloride is converted to chlorate and perchlorate.

An outline of the electrolytic pretreatment unit designed and fabricated under Contract No. NAS1-11781 is shown in Figure 2. The unit has been designed to process urine and flush water for a crew of six. Based on a urine output of 3.45 lb/man-day and a flush water usage of 0.86 lb/man-day, the unit is designed to process 25.86 lb/day. The design process rate is set at 3.22 lb/hr

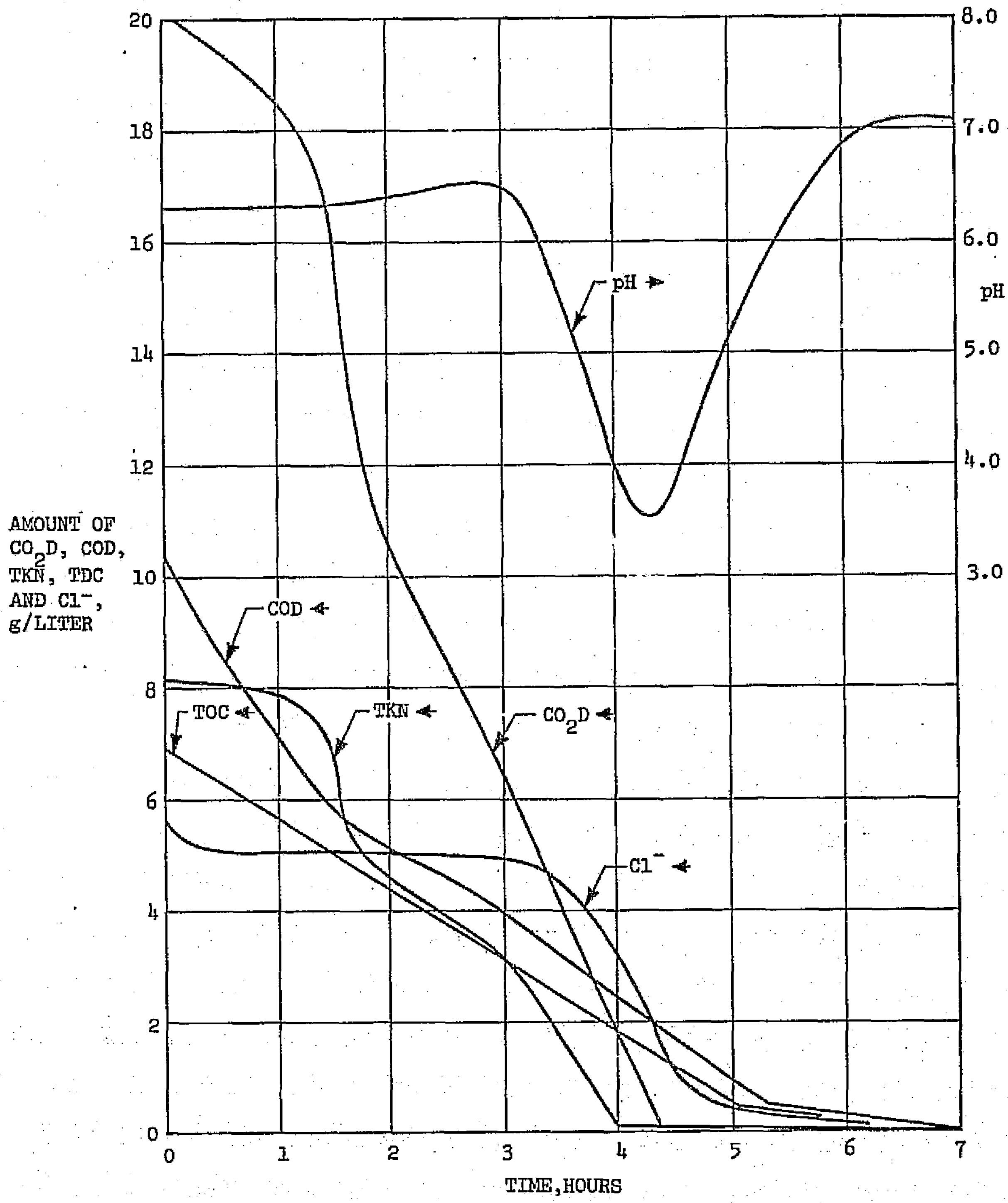

Figure 1. Chemical Analysis of Urine During Electrolytic Pretreatment

Table 1

AN ANALOG REPRESENTING THE SALTS REMAINING AFTER ELECTROLYTIC PRETREATMENT OF TYPICAL HUMAN URINE

Item	Formula	Formula Weight	Amount (mg/liter)
Sodium chloride	$NaCl$	58.4	1,542
Sodium chlorate	$NaClO_3$	106.5	5,314
Sodium perchlorate	$NaClO_4$	122.5	7,436
Potassium perchlorate	$KClO_4$	138.6	776
Potassium sulfate	K_2SO_4	174.3	4,497
Potassium nitrate	KNO_3	101.1	162
Magnesium chlorate	$Mg(ClO_3)_2 \cdot 6H_2O$	299.3	2,454
Potassium phosphate	K_3PO_4	213.3	234
Calcium phosphate	$Ca_3(PO_4)_2$	310.2	62
			22,477

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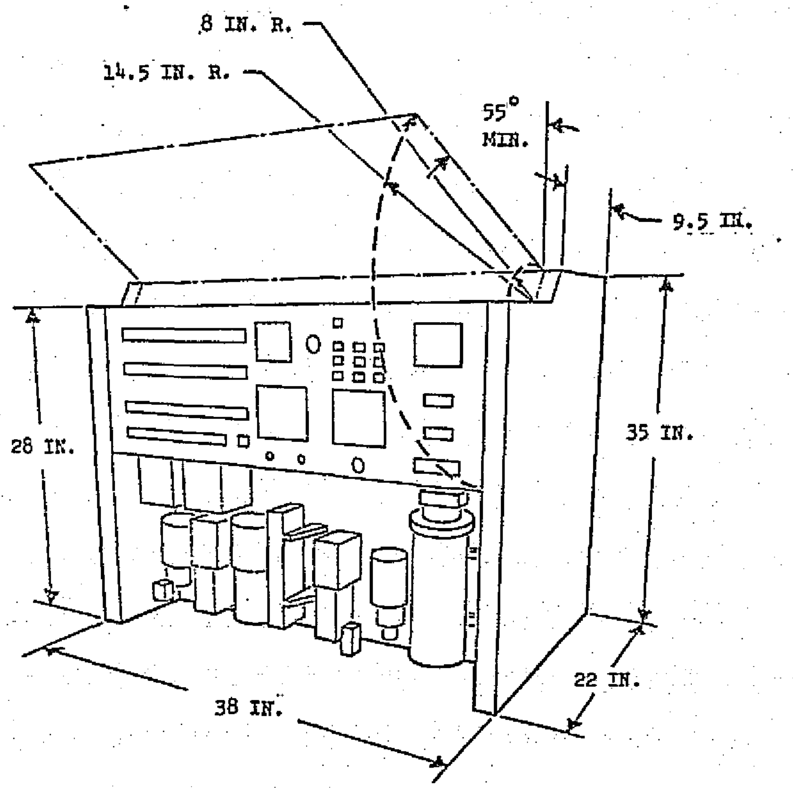

Figure 2. Outline Drawing of Electrolytic Pretreatment Unit

so that each day's urine output can be pretreated in eight hours to allow for make-up processing in the event of a unit malfunction (Reference 3). A schematic of the unit is shown in Figure 3.

As the electrolysis reaction progresses, the electrolytic pretreatment process produces by-product gases which could be reused if their selective separation could be achieved by efficient and low-cost methods. Table 2 lists the gas quantities produced in tests conducted under Contract No. NAS1-8954. The necessary tests will be conducted in the program described in this appendix to verify that the large batch sizes to be processed in the EPU do not result in significantly altered by-product gas compositions. A comprehensive plan to evaluate the feasibility of reclaiming these gases is presented in Reference 4. This plan could be conducted concurrently with the proposed program.

Figure 4 shows the major gas constituents as the electrolysis of 4-liter batches of urine progressed (Reference 3). The O_2 volume fraction of the gas was found to be a reliable indicator of the level of TOC reduction in the electrolysate. Figure 5 shows the TOC level from Figure 1 with the by-product O_2 gas fraction from Figure 4. Figure 5 indicates that the evolved gas O_2 content should be a reliable indicator of TOC control for TOC levels less than approximately 3.5 mg/liter. A polarographic oxygen sensor has been installed in the EPU vent gas line to test this method of process control. Tests will also be conducted to determine the degree of electrolytic pretreatment required for various distillation temperatures.

Since some excess chlorine is given off in the electrolysis reaction, the possibility of using this gas to sterilize the raw urine held in the urine storage tank will be evaluated. This will be done by routing the vent gas from the electrolysate tank through a bubbler located at the bottom of the urine tank.

Previously, variations in applied voltage have been used to control cell current density for electrolytic pretreatment tests that are applicable to space. This method of current control utilizes relatively inefficient auxiliary electrical control networks and is undesirable for space application. As the electrolysate conductivity remains relatively constant during the electrolysis process, the EPU multiple electrode design will allow a series/parallel electrical configuration using unregulated 28-vdc power. Various electrolysate hydraulic configurations will also be investigated to identify the best combination of package size and liquid/gas flow patterns for efficient operation.

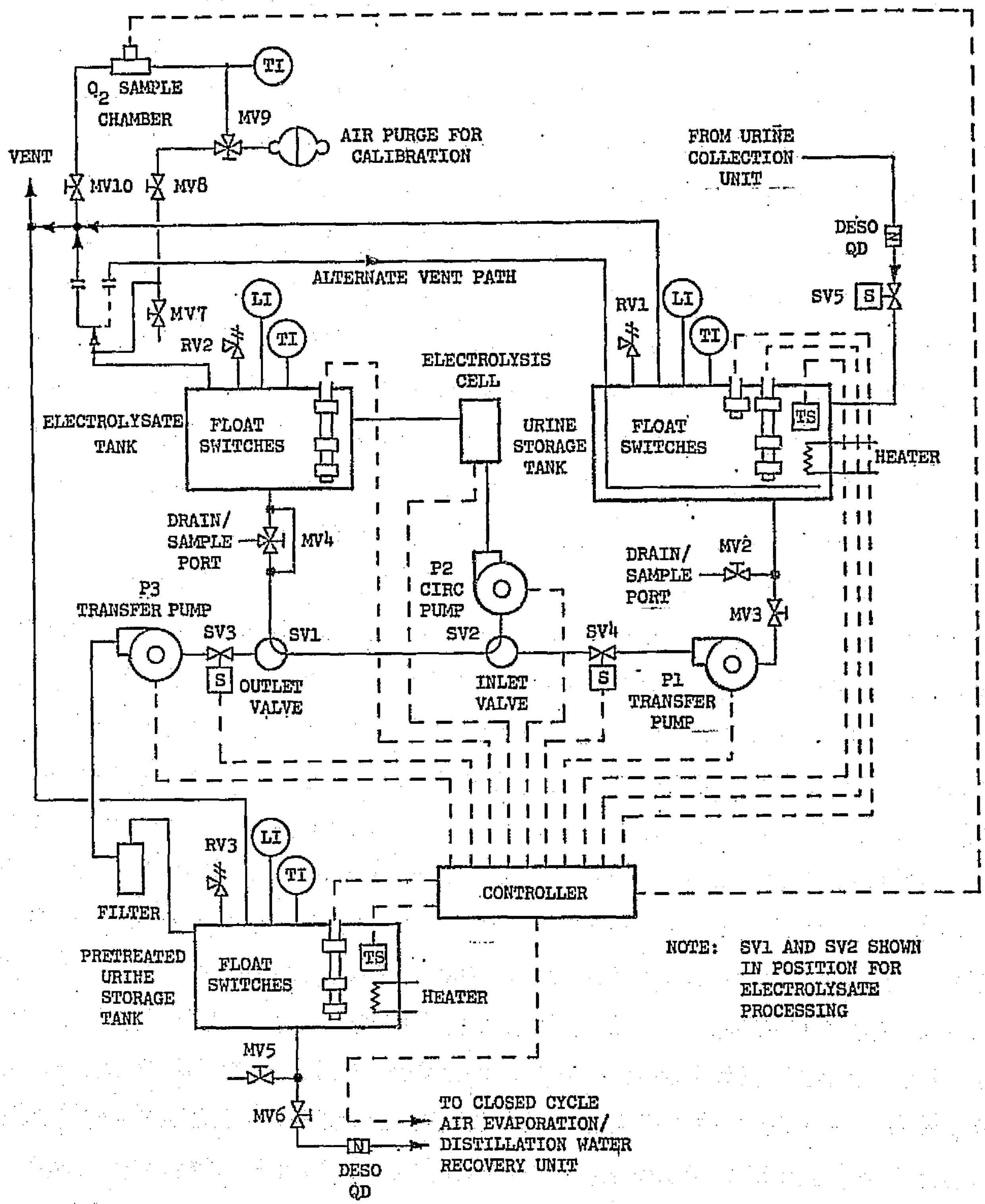

Figure 3. Schematic of Electrolytic Pretreatment Unit

Table 2

QUANTITY OF GASES GENERATED BY THE ELECTROLYTIC PRETREATMENT PROCESS
(assumes 0.165 lb of urine solids per man-day)

Gas	Amount (lb/man-day)
CO_2	0.10
O_2	0.036
N_2	0.031
H_2	0.014
Cl_2	0.0012
H_2O	0.00055
CO	0.00018
HCl	0.000008
NH_3	0.000008
NO_2	0.00000016
O_3	0.000000012
$COCl_2$	0
SO_2	0
H_2S	0
HCN	0
Chloroform	Trace
Isopropyl alcohol	Trace
Ethylene dichloride	Trace
Tertiary butyl alcohol	Trace
Amyl alcohol	Trace
Dichloromethane	Trace

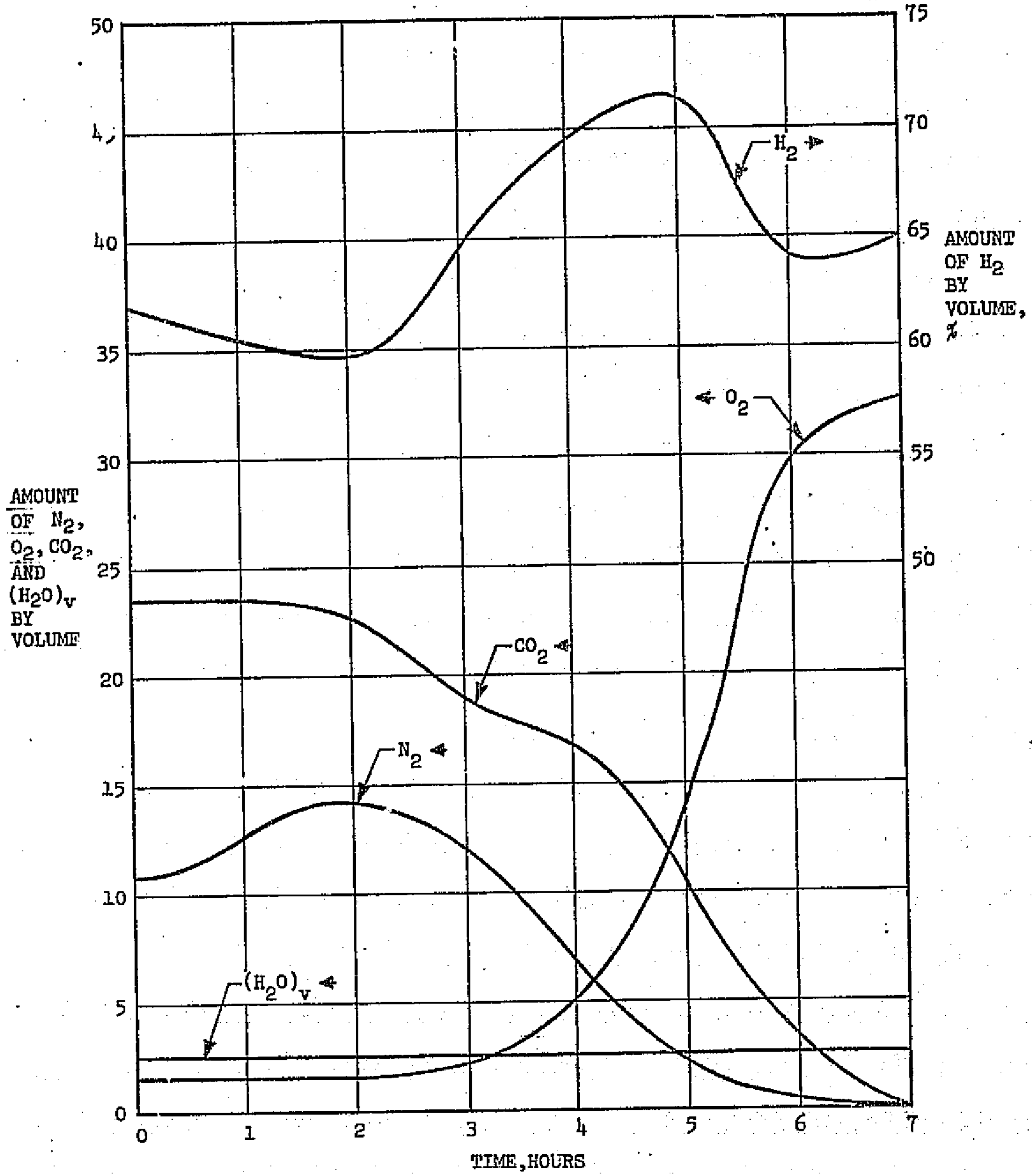

Figure 4. Composition of Gas Output During Electrolytic Pretreatment

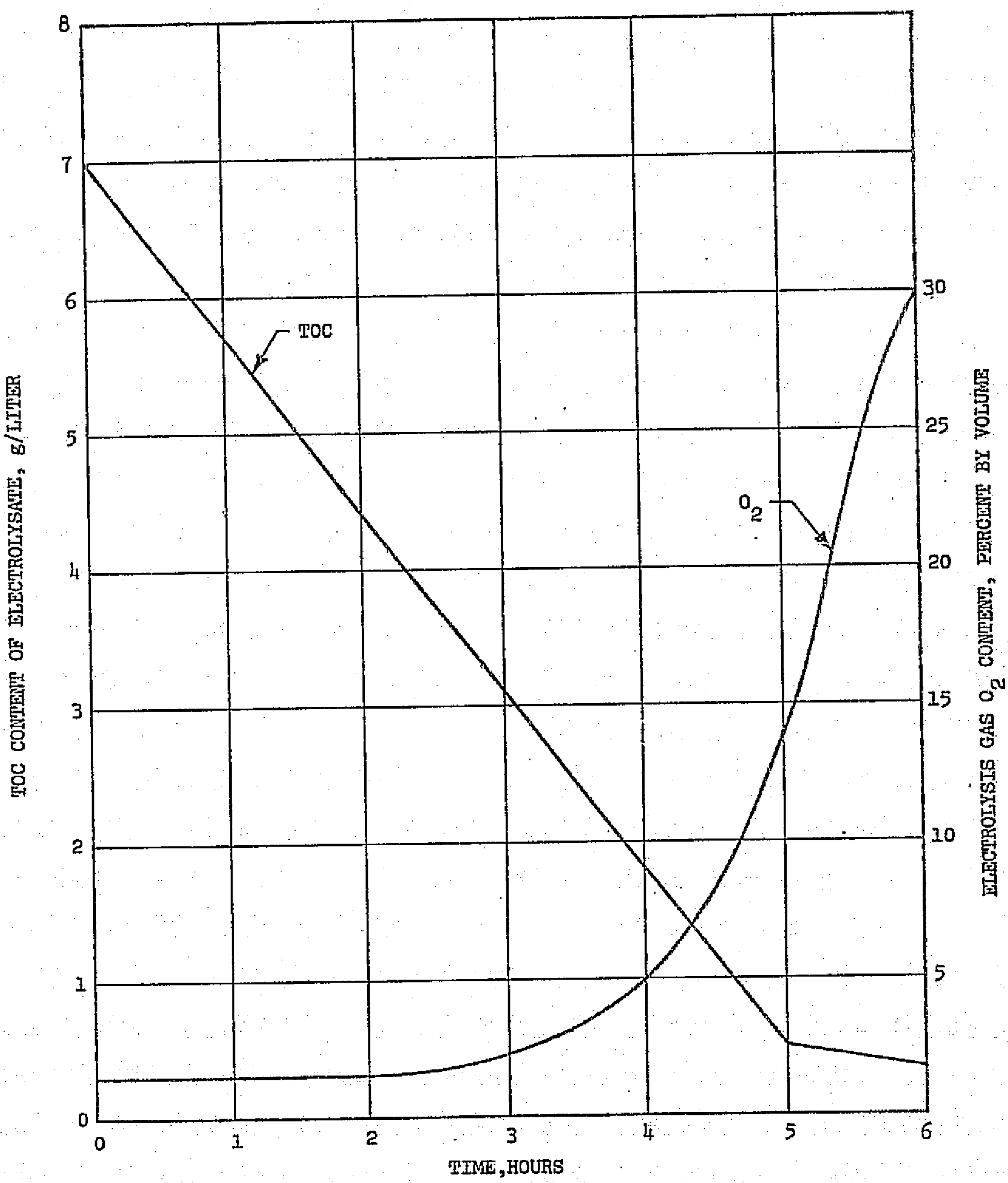

Figure 5. Variation in Electrolysate TOC Content and Electrolysis Gas O_2 Content with Processing Time

In order that a realistic comparison may be made between chemical pretreatment and electrolytic pretreatment, the energy and power profiles of the EPU operation will be closely monitored.

2.2 AIR EVAPORATION UNIT

In the air evaporation process, urine is evaporated into a warm airstream that is subsequently cooled below its dew point to yield a condensate, which, with additional posttreatment if needed meets the current standards of the National Academy of Science and National Research Council (NAS-NRC) for spacecraft potable water. (The standards currently in effect may be found in Appendix B of Reference 5.)

Both the open and closed air evaporation cycles have been investigated in the laboratory, in bench tests, and in manned chamber runs. Definitions of the open and closed cycles are as follows (Reference 6).

Open-Cycle Air Evaporation—Urine is evaporated into an airstream that is drawn from the cabin and discharged back to it. Cabin humidity is condensed simultaneously with the urine distillate. A separate humidity control loop is not required.

Closed-Cycle Air Evaporation—Urine is evaporated into a closed-cycle recirculating air loop (a separate humidity control circuit is required for space vehicle application). An air charcoal bed is included to produce water of the same quality as obtained in the open-cycle system.

A closed-cycle air evaporation approach was selected for evaluation with the EPU. A flow diagram of the unit is shown in Figure 6 and an outline drawing of the unit in Figure 7. The design point for the closed-cycle air evaporation unit to be tested with the EPU is as follows:

Urine feed rate: 3.22 lb/hr

Inlet air temperature: 200°F

Inlet air dew point: 80°F

Design point effectiveness (η) = 0.72 = ratio of the actual amount of water evaporated to the theoretical amount which could be evaporated.

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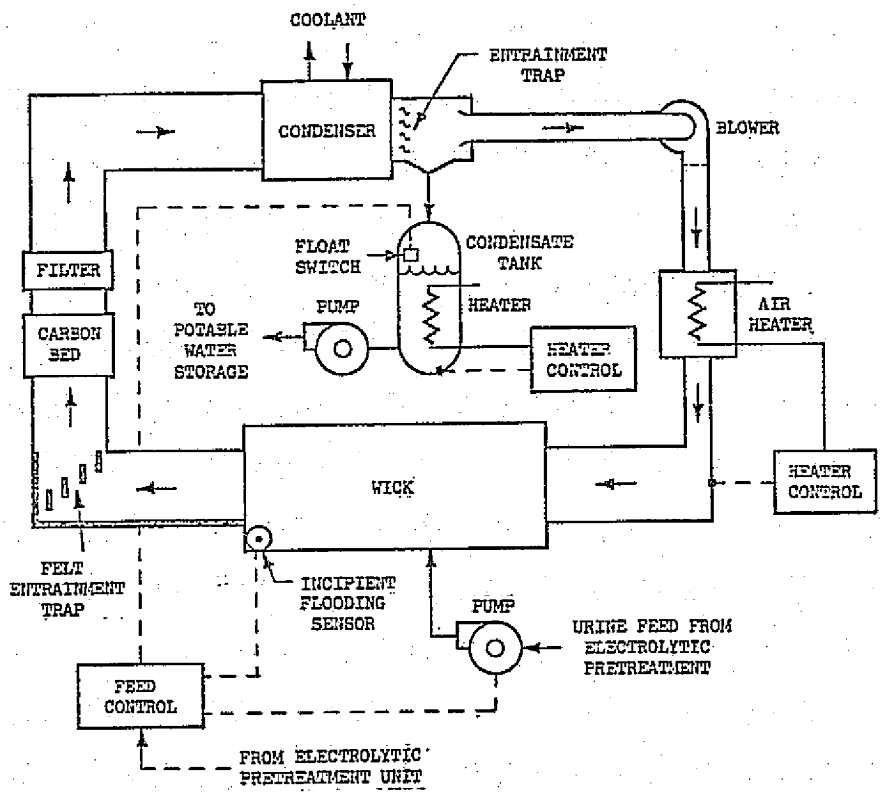

Figure 6. Flow Diagram of Air Evaporation Unit

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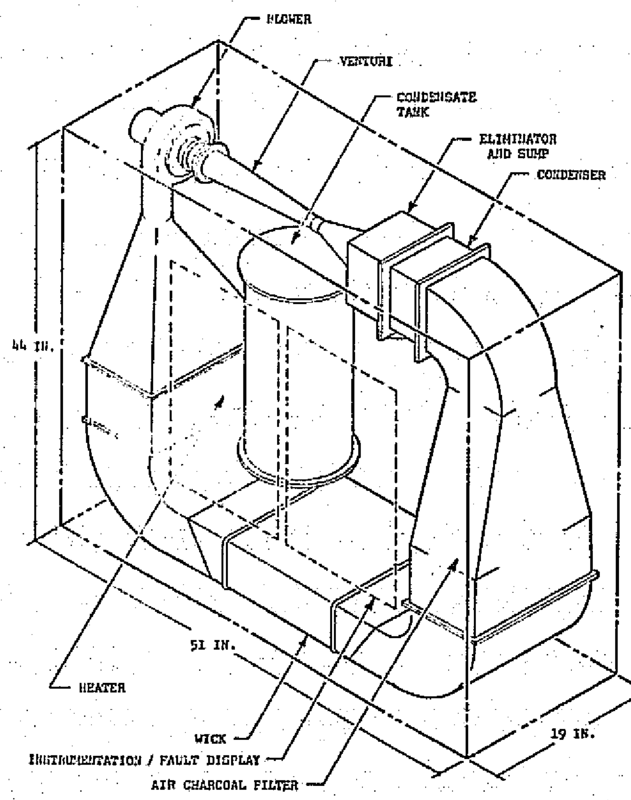

Figure 7. Outline Drawing of Air Evaporation Unit

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The projected AEU performance map is shown as Figure 8 (Reference 7). Actual data from MDAC testing of open-cycle air evaporation units using chemical pretreatments with similarlv designed wicks correlate well with Figure 8 (Reference 8). This provi a good baseline for comparisons of experimental test results using el rolytic pretreatment.

To achieve the maximum solids loading in each wick, the incoming urine must be distributed uniformly throughout the wicking material. MDAC has conducted extensive tests (Reference 9) with independent research and development (IRAD) funds to determine the best urine manifold configuration for proper urine distribution. These tests were conducted under IRAD Program Account No. 80602-016 and 80602-301.

In addition to proper manifold design, the instantaneous flow rate of the urine and injection pump on/off cycle times are important parameters in obtaining good distribution of solids. Tests will be conducted on the completed air evaporation unit to determine optimum feed cycles using distilled water and the incipient flooding sensor installed in the wick package. These tests will

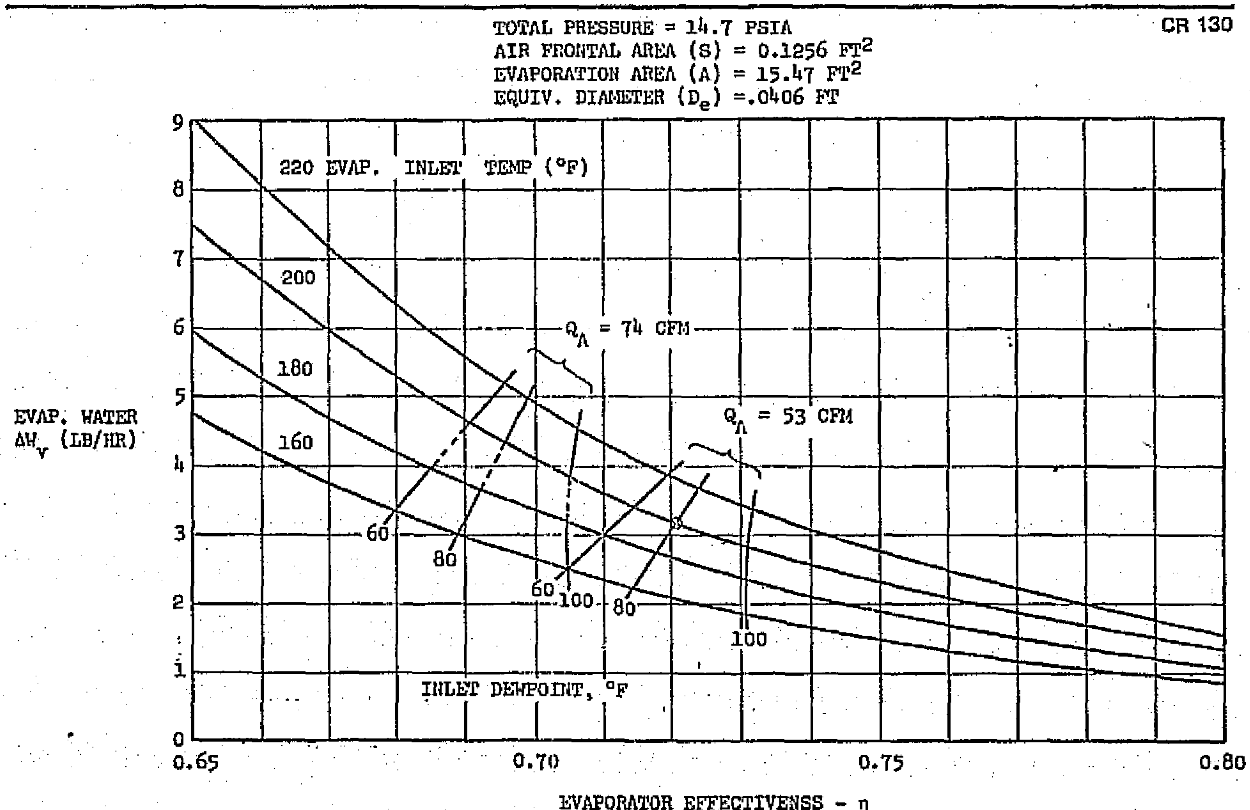

Figure 8. Theoretical Performance Map of Air Evaporation Unit

be made with IRAD funds. The data obtained from these IRAD tests will be used as a baseline for additional testing conducted in this program.

Raw urine has a solids content of approximately 37,000 g/liter and electrolytically pretreating the urine results in a reduction in solids content to about 20,000 mg/liter (depending on processing time). Wick life tests will be conducted to determine if this reduction in solids content results in increased wick life. Tests will also be conducted to determine the maximum limit to which pretreated urine brine may be concentrated and still produce acceptable water. The temperature-dependence of this limit will also be determined.

The distillate obtained from the closed-cycle air evaporation unit will be analyzed chemically and microbiologically and compared to distillate obtained from chemically pretreated urine. The posttreatment polishing requirements, if any, to meet potability standards will be defined.

Energy and power profiles of the closed-cycle AEU will be taken for comparison with existing data (Reference 8) for open-cycle systems. At the conclusion of the test program, the system will be disassembled, microbial samples will be taken to obtain sterility data, and an assessment made of the long-term corrosive effects of the vapor and distillate on the AEU components.

Section 3
STATEMENT OF WORK

MDAC will provide all personnel, materials, services, equipment, and facilities required to conduct the 12-month program in Huntington Beach, California, to test a GFE electrolytic pretreatment unit with an MDAC-provided closed-cycle air evaporation unit. This program will be carried out in eight major tasks. The tasks correspond to those time-phased on the schedule appearing in Section 4.

3.1 TASK I TEST-PROCEDURE DOCUMENT

The detailed plans for the combined electrolytic pretreatment unit/closed-cycle air evaporation unit test program will be prepared and 10 copies will be submitted to the contract monitor three months from the contract award date. This document will define in depth the methods, procedures, measurements, and analyses required to conduct the tests described in Sections 3.4 through 3.7. Where possible, the tests will be structured to operate unattended in non-first-shift hours so that around-the-clock testing may be carried out in a cost-effective manner. Attention will be given to all aspects of test operation to ensure that personnel and equipment are not endangered by component malfunctions.

The test procedure document will define measurement locations, measurement devices, chemical and microbial sampling and analysis techniques, data display devices, and the frequency of data monitoring. Sufficient detailed information will be presented in the test procedure document to ensure that test personnel perform all required test operations and that deviations from the planned test sequences are minimized.

3.2 TASK 2-DATA SYSTEM DESIGN

The data system required to characterize the EPU/AEU performance will be defined and a detailed design prepared. An integrated EPU/AEU system

schematic similar to that shown in Figure 9 will be prepared to indicate measurement locations.

A finalized instrumentation list will be prepared with measurement identification keyed to the integrated schematic. The final instrumentation list will be similar to the preliminary list shown in Table 3. The types of transducers and signal conditioning equipment will be selected, and sufficient detailed working and assembly drawings will be prepared to permit fabrication and assembly of the data system. Separate electrical drawings will be prepared to permit construction of the signal conditioning and cabling networks required. Parts having long lead times will be purchased during the performance of this task.

3.3 TASK 3-DATA SYSTEM FABRICATION, INTEGRATION, AND CHECKOUT

Using the detailed working drawings developed during Task 2, the contractor will construct the proposed data system. On completion of data system fabrication, the electrolytic pretreatment unit and the air evaporation unit will be integrated with the data system. Electrical and mechanical connections will be made between the units and the data system, and the components checked to ensure their continuity and integrity. Sample test data will be taken immediately after system startup to ensure that all data points are recording properly and that all components in the system are operating in a normal manner.

3.4 TASK 4-PRETREATMENT REQUIREMENTS TESTS

A series of tests will be run to determine the degree of pretreatment required for use in the AEU and to determine if the degree of pretreatment is a function of wick inlet air temperature. Each test will begin with a dry wick which will then be saturated by adding an amount of pretreated urine sufficient to cause saturation. The wick will then be dried in the AEU with the output water conductivity continuously monitored. The evaporator will be operated at a constant wick inlet temperature of 140 °F for eight wick saturation/dry-down cycles (two each for urine pretreated to total organic carbon (TOC) levels of 6, 4, 1.5, and 0.5 g/liter). Chemical and microbial analyses shown in Table 4 will be performed on the reclaimed water collected from the feed solution containing 6 g/liter TOC. Additional chemical and microbial analyses will be performed for this test series only if the conductivity-versus-percent-

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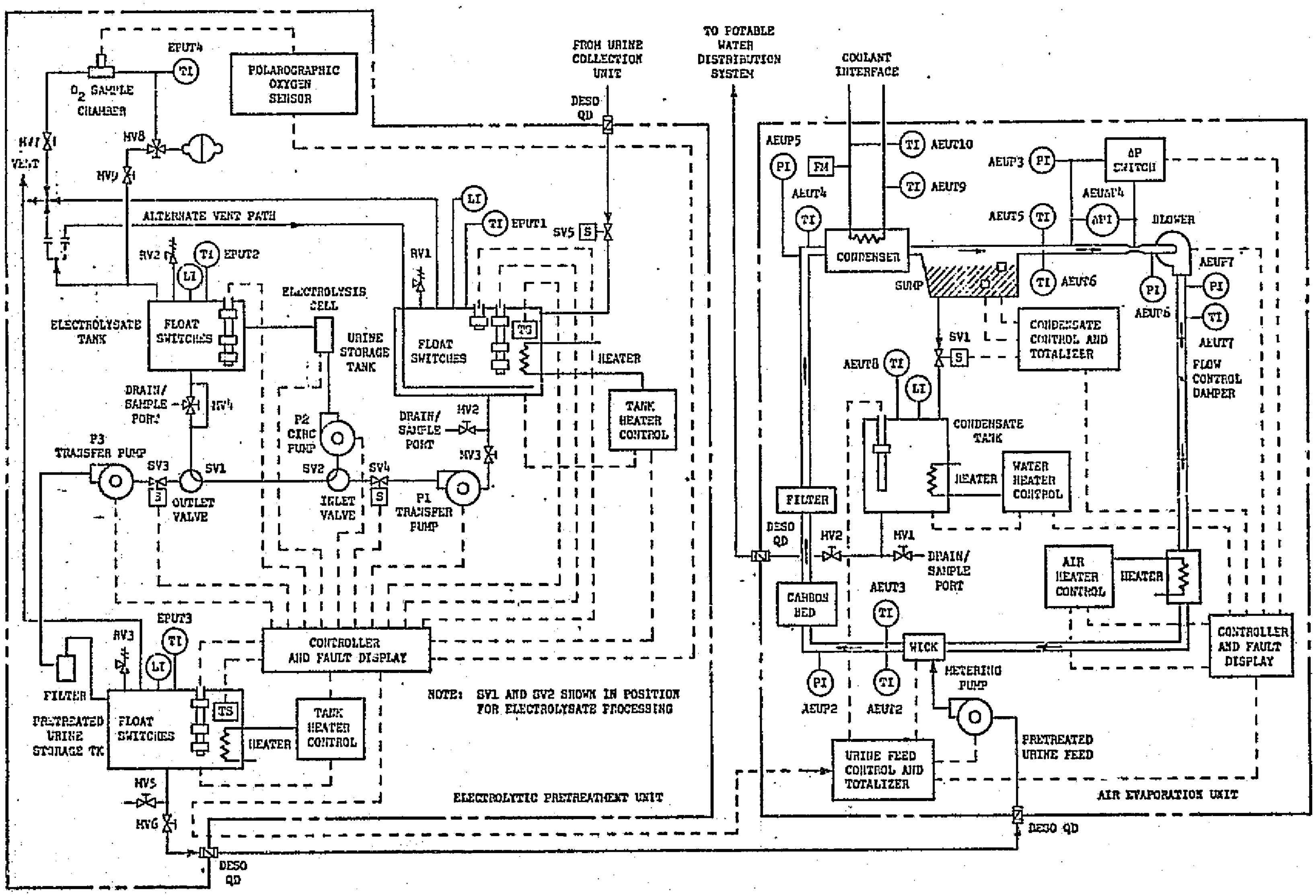

Figure 9. Schematic of Electrolytic Pretreatment/Air Evaporation Unit

Table 3 (Page 1 of 2)

PRELIMINARY INSTRUMENTATION SCHEDULE

Unit	Ident Key	Item	Data Recording Frequency	Instrument	Type Data Readout
EPU		Unit ac energy	Twice per working day	Watt-hour meter	Visual indicator
		Unit dc power	Continuous	Watt meter	Strip chart
	EPUT 1, 2, 3	Tank temperature	Twice per working day	Pyrometer	Visual indicator
		Vent gas O_2 content	Continuous	Polarographic oxygen analyzer	Strip chart
		Vent gas composition	As required	Gas chromatograph	Strip chart
		Feed and product chemical analyses	As required	Various	Various
	EPUT 4	Vent gas temperature	Twice per working day	Pyrometer	Visual indicator
AEU		Heater energy	Continuous	Watt-hour meter	Visual indicator
	AEUP 1 through AEUP 7	Flow loop air pressures	Twice per working day	Pressure gage	Visual indicator
		Injection pump cycles	Twice per working day	Cycle counter	Visual indicator
	AEUDP 4	Flow-loop airflow	Twice per working day	DP gage	Visual indicator
	AEUFM 1	Condenser coolant flow	Twice per working day	Flow transducer	Visual indicator
	AEUT 9, 10	Condenser coolant temperature	Twice per working day	Pyrometer	Visual indicator

Table 3 (Page 2 of 2)

PRELIMINARY INSTRUMENTATION SCHEDULE

Unit	Ident Key	Item	Data Recording Frequency	Instrument	Type Data Readout
		Condenser output water quantity	Continuous and twice per working day	Cycle counter	Strip chart and visual indicator
	AEUT 8	Condensate tank temperature	Twice per working day	Pyrometer	Visual indicator
		Condensate conductivity	Continuous	Conductivity meter	Strip chart
	AEUT 1	Wick inlet temperature	Twice per working day	Pyrometer	Visual indicator
	AEUT 2, 3	Wick outlet (temperature (wet bulb/dry bulb)	Twice per working day	Pyrometer	Visual indicator
	AEUT 4	Condenser inlet temperature	Twice per working day	Pyrometer	Visual indicator
	AEUT 5, 6	Condenser outlet temperature (wet bulb/dry bulb)	Twice per working day	Pyrometer	Visual indicator
	AEUT 7	Heater inlet temperature	Twice per working day	Pyrometer	Visual indicator
		Wick outlet dew point	Continuous	Dew point indicator	Strip chart
		Wick inlet dew point	Continuous	Dew point indicator	Strip chart
		Unit ac energy (1 phase)	Continuous	Watt-hour meter	Visual indicator
		Unit dc power	Continuous	Watt meter	Strip chart

Table 4

CHEMICAL AND MICROBIAL ANALYSIS TESTS

Item	Measurement Unit
Total organic carbon	mg/liter
Specific conductivity	μmho-cm^{-1}
pH	pH units
Ammonia	mg/liter
Turbidity	Jackson units or ppm $Si\ 0_2$
Color	Pt -- Co units
Foaming	Time of persistance
Odor	Subjective evaluation
Taste	Subjective evaluation
Total dissolved solids	mg/liter
Urea	mg/liter
Lactic acid	mg/liter
NaCl	mg/liter
Sodium	mg/liter
Potassium	mg/liter
Calcium	mg/liter
Iron	mg/liter
Magnesium	mg/liter
Chromium	mg/liter
Microbial contamination	Number per standard 48-hr plate

wick-saturation curve varies significantly from the initial curve. The wick inlet temperature will then be raised to the next test condition and the series repeated. Table 5 shows a schedule of test conditions to be followed for this task.

During this task, the vent gases will be passed through the urine storage tank and sufficient microbial samples taken to evaluate the ability of the excess chlorine in the vent gases to maintain system sterility with the urine storage tank at ambient temperature.

Should the tests conducted in this task indicate the desirability of post-treatment polishing to meet NAS-NRC spacecraft potable water quality standards, a breadboard polishing bed will be fabricated and used in the remaining tests.

Table 5

PRETREATMENT REQUIREMENTS TEST SCHEDULE

Test Number	Wick Inlet Temperature (°F)	Condenser Temperature (°F)	TOC Content of Feed (mg/liter)
1, 2	140	50	6.0
3, 4			4.0
5, 6			1.5
7, 8			0.5
9, 10	160	50	6.0
11, 12			4.0
13, 14			1.5
15, 16			0.5
17, 18	180	50	6.0
19, 20			4.0
21, 22			1.5
23, 24			0.5

3.5 TASK 5-FEED CYCLE TESTS

During the operational verification tests of the AEU (conducted with MDAC IRAD funds), distilled water will be used to find the preferred wick injection pump pressure, on-off cycle frequency, and on-cycle duration. Additional tests will be performed to verify the applicability of the water injection test results when feeding pretreated urine. Injection pump instantaneous flow rates of 1.5 to 20.0 liters per hour will be investigated with pump-on times between 1 and 60 seconds and off times between 1 and 360 seconds. Pump flow rate and on-off cycle times to be investigated are listed in Table 6. The wick discharge dew point will be monitored along with wick incipient flooding indicator signals to determine desirable injection characteristics for normal conditions as well as maximum rates for make-up processing. The most favorable feed modes determined for the design wick inlet temperature and air-flow rate will be evaluated at air-flow rates below and above the design point and temperatures below the design point to determine feed mode sensitivities to off-normal conditions. The test sequence for the feed mode sensitivity tests will be as shown in Table 7.

3.6 TASK 6-PARAMETRIC TESTS AND WICK LOADING PROFILES

Wick loading tests will be run at the degree of urine pretreatment determined from Task 4 and the preferred feed cycle and flow rate determined from Task 5. A constant air-flow rate at the design point will be maintained for all tests. Each test will be started by saturating a preweighed, clean, dry wick with a predetermined quantity of pretreated urine. The wick will then be run under constant inlet temperature, air-flow rate, and condenser temperature conditions until either output water quality fails to meet NAS-NRC standards or until a feed flow rate of 370 mliter/hr cannot be maintained due to wick flooding. The incipient flooding indication system will be on line for this test. When the wick fails to meet either the NAS-NRC water quality standards or to maintain the minimum process rate (370 mliter/hr), it will be dried thoroughly and weighed. Photographs will be taken of the wick sections to record the distribution of visible solids, and each fourth wick felt segment will be cut into 40 equal pieces and weighed to determine quantitative distribution of solids.

Table 6

INITIAL FEED CYCLE TEST PARAMETERS

Injection Pump Instantaneous Flow Rate	20.0 liters/hr		10.0 liters/hr		4.0 liters/hr		2.0 liters/hr		1.50 liters/hr	
Injection pump on-and-off cycle times for 1.46 liters/hr injection flow	Pump On Time (sec)	Pump Off Time (sec)	Pump On Time (sec)	Pump Off Time (sec)	Pump On Time (sec)	Pump Off Time (sec)	Pump On Time (sec)	Pump Off Time (sec)	Pump On Time (sec)	Pump Off Time (sec)
	29	331	54	306	-	-	-	-	-	-
	12	133	22	122	52	92	105	39	140	4
	3	33	5	31	13	23	26	10	35	1
	-	-	-	-	1	2	3	1	Continuous	-

Table 7

SEQUENCE FOR FEED MODE SENSITIVITY TESTS

	Air Flows		
Temperature	Low	Design	High
140 °F	4	5	6
180 °F	9	8	7
200 °F (Design)	3	1	2

Tests 2 through 9 to be made using feed mode determined most favorable at conditions of Test 1.

Output water conductivity will be continuously monitored, and a chemical and microbial analysis of the items listed in Table 5 will be performed as required, but not more often than once per day.

Data will be taken to determine EPU and AEU system power profiles and the fraction of input water recovered. Chemical analysis of the electrolytic pretreatment vent gases will be performed using gas chromatography to identify the amounts of nitrogen, oxygen, chlorine, carbon dioxide, and hydrogen generated during electrolytic pretreatment. Should these tests produce data that differ significantly from Table 2, additional tests will be conducted to to characterize the vent gas.

To obtain statistically significant results, two wicks will be operated to the end of their useful lives at each of four wick inlet temperatures: 140 °, 160 °, 180 °, and 200 °F. The sequence of tests to be performed is shown in Table 8.

3.7 TASK 7-MAXIMUM PROCESS RATE AND OFF-NORMAL OPERATIONING CONDITIONS TESTS

Based on the results obtained from the previous tests (Tasks 4 through 6), a series of tests will be run to determine the maximum EPU/AEU output rate

Table 8

SEQUENCE FOR WICK LOADING TESTS

Inlet Air Temperature (°F)	Test No.	
140	3	7
160	4	6
180	1	5
200	2	8

Note:

A. Design air flow rates to be used for all tests.

B. TOC level in feed to be as determined from Task 4.

C. Feed rate to be as determined from Task 5.

D. Each wick to be run until product no longer meets NAS-NRC standards or until 370 mliter/hr process rate cannot be maintained due to flooding.

of water meeting NAS-NRC standards. Power profiles will be monitored during these tests to determine the impact of system efficiency on operation at these rates.

Tests will also be conducted to evaluate the effects of reduced inlet temperature (simulated reduced heater output) and reduced air flow (simulated duct blockage).

At the conclusion of these tests, the EPU and AEU will be disassembled. Microbial swab samples will be taken of the inner surfaces of the three EPU tanks and of the surface of the inner duct and storage tank of the AEU to assess long-term system sterility. Aerobic and anerobic bacterial (mesophillic) contaminants as well as fungal types will be investigated. Presumptive identification of isolates will be made using colonial morphology and microscopic examination of gram-stained smears.

3.8 TASK 8-REPORTS

Task 8.1-Monthly Reports

An informal letter-type report will be submitted by the 10th day of the month following ATP and by the 10th day of each month thereafter until the contract work is completed. These monthly reports will summarize work done on the contract in the previous month, work to be done in the next reporting period, and the technical and schedule status of the program. Monthly progress reports will not be submitted for the month in which the draft final report is submitted, the month in which the final report is being reviewed by the contracting agency, and the month in which the final report is distributed.

Task 8.2-Final Report

At the conclusion of the contract, a final report will be submitted. It will provide a historical narrative of all work accomplished during the contract. Graphs, photographs, tables, and other information will be used to describe the work in the most accurate and concise manner possible. Drawings will be included in reduced size, wherever appropriate.

Operating characteristics will be calculated from the test data, and comparisons will be made from existing data to show such factors as (1) the amount of pre-treatment chemicals required for equivalent operating periods, (2) EPU/AEU power profiles as compared to chemical pretreatment/air evaporation power profiles, and (3) the increase in air-evaporator wick life resulting from removal of partial solids and organics during electrolytic pretreatment. The final report will be published after a review copy has been approved by the contracting agency. Following approval, MDAC will print and distribute 50 copies of the final report in accordance with a distribution list to be supplied by the contracting agency.

3.9 SUBCONTRACTS AND PROCUREMENT

MDAC does not anticipate using any subcontractors on the proposed program. Procurement of materials and services will be made in accordance with established Company practices.

3.10 GOVERNMENT-FURNISHED EQUIPMENT

The GFE to be used in this program on a no-cost, noninterference basis consists of one electrolytic pretreatment unit developed by MDAC for NASA under Contract No. NAS1-11781. The unit is to be provided for the duration of the contract. This unit is presently in-house at MDAC.

Section 4
SCHEDULE

The proposed program schedule is shown in Figure 10. Some of the key goals of the proposed program have been designated as milestones and are so indicated on the schedule. The tasks time-phased on the schedule correspond to those outlined in Section 3.

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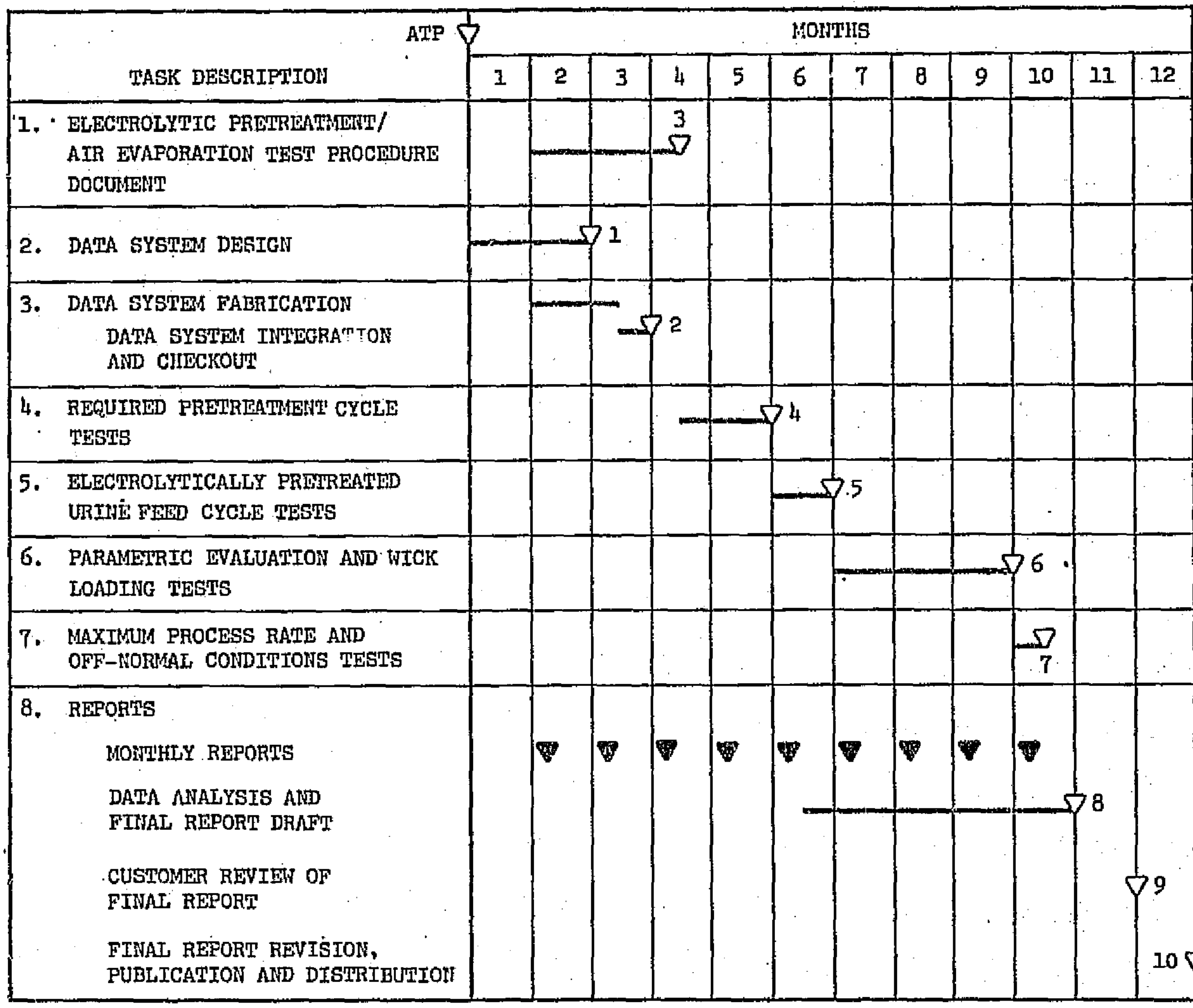

MILESTONES

1. DATA SYSTEM DESIGN COMPLETE
2. DATA SYSTEM FABRICATION COMPLETE
3. TEST PROCEDURE DOCUMENT COMPLETE
4. PRETREATMENT CYCLE TESTS COMPLETE
5. FEED CYCLE TESTS COMPLETE
6. PARAMETRIC EVALUATION AND WICK LOADING TESTS COMPLETE
7. MAXIMUM PROCESS RATE AND OFF- NORMAL TESTS COMPLETE
8. FINAL REPORT DRAFT SUBMITTED FOR REVIEW
9. CUSTOMER REVIEW OF FINAL REPORT COMPLETE
10. FINAL REPORT PUBLISHED AND DISTRIBUTED

Figure 10. Program Schedule

Section 5
REFERENCES

1. Design and Fabrication of a Flight Concept Prototype Electrochemical Water Recovery Subsystem, NASA CR-111961, Sept. 1971.

2. D. F. Putnam and R. L. Vaughan. Water Reclamation from Urine by Electrolysis-Electrodialysis, MDAC Paper WD 1594, Apr. 1971.

3. Combination of an Electrolytic Pretreatment Unit With Secondary Water Reclamation Processes, Preliminary Design Report, MDC G3851, Sept. 1972.

4. Electrolytic Pretreatment Gas Conditioning Study, MDC G4162, Mar. 1973.

5. Definition of Reverse Osmosis Requirements for Spacecraft Wash Water Recycling, MDC G3780, Nov. 1972.

6. D. F. Putnam. Status Report on the Air Evaporation Technique for Spacecraft Water Recovery, unpublished MDAC report, Sept. 1968.

7. Water Recovery for Spacecraft Applications, MDC G4338, Jan. 1973.

8. Test Report and Test Results of an Operational Ninety-Day Test of a Regenerative Life Support System, NASA CR 111881 (MDC G2282), May 1971.

9. Development Tests of the Air Evaporation Water Recovery System, MDC G0991, Apr. 1971.

Appendix C

CONTRACT STUDY SUBTASK 4.6F

A PROGRAM TO DEFINE THE REQUIREMENTS OF A COMBINED ELECTROLYTIC PRETREATMENT/REVERSE OSMOSIS SYSTEM FOR SPACECRAFT POTABLE WATER RECOVERY

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MDC G4229

A PROGRAM TO DEFINE THE REQUIREMENTS OF A COMBINED ELECTROLYTIC PRETREATMENT/REVERSE OSMOSIS SYSTEM FOR SPACECRAFT POTABLE WATER RECOVERY

August 1973

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Prepared Under Contract No. NAS1-11781
for
Johnson Space Center
National Aeronautics and Space Administration

PREFACE

This document reviews the applicability of a combined electrolytic pretreatment/reverse osmosis system for the reclamation of potable water from human urine. A Work Statement is presented which outlines a plan for a comprehensive evaluation of the advantages of this combined system.

CONTENTS

FIGURES

TABLES

Section 1
INTRODUCTION AND SUMMARY

Potable and wash water requirements for long-duration space missions impose the greatest weight and volume penalties of all life support requirements unless recycle systems are employed. One technique which appears very promising for water recovery during space missions is the membrane separation technique known as reverse osmosis (Reference 1).

The advantages of reverse osmosis for water recovery in space missions include:

A. The process is basically simple, with no two-phase mixtures or separators required.
B. It has the potential for trouble-free operation with a minimum of attention needed and uses simple control networks.
C. It presents no zero-g problems.
D. Membranes may be fabricated with a wide variety of rejection characteristics, allowing the system to be tailored to remove specific solutes.

To the present, most studies have considered reverse osmosis as a viable candidate for spacecraft wash water recovery (References 1 and 2). However, primarily due to high operating pressure requirements and poor rejection characteristics for urea, the reverse osmosis process has been discounted as a means of reclaiming potable water from urine. These limitations may now be overcome with the use of the electrolytic pretreatment process (References 3 and 4) developed by MDAC for NASA (under Contracts NAS1-7104, NAS1-8954, and NAS1-11781). This process has the capability of lowering pressure requirements for reverse osmosis and of removing all organics, including urea, from urine.

A plan is presented in this report to evaluate the benefits of combining the electrolytic pretreatment process with reverse osmosis to reclaim potable water from human urine. This could be accomplished in a cost-effective manner with a combination of analytical studies and experimental tests, and utilizing equipment now being fabricated under related Government contracts.

Section 2
TECHNICAL DISCUSSION

Studies conducted by MDAC under Contract No. OSW 14-30-3062 have shown that spacecraft wash water reclamation by reverse osmosis is technologically feasible and is cost-competitive with other methods of spacecraft wash water recovery (Reference 2). The benefits of wash water recovery by reverse osmosis may also be extended to spacecraft potable water recovery, although additional work is required to solve its unique problems in processing urine. The advantages of applying reverse osmosis to urine reclamation are clear: The power and working volume requirements of a potable water phase-change process could be almost halved by the use of an upstream reverse osmosis system recovering only 50 percent of its input feed. Should the reverse osmosis recovery fraction be significantly greater than 50 percent, it might be feasible to eliminate the phase-change process.

The work outlined in this report will identify the most favorable combination of electrolytic pretreatment and reverse osmosis for potable water recovery by a program consisting of: (1) analyses of projected system performance; (2) launch weight and total relative cost tradeoff comparisons, and (3) experimental laboratory tests conducted with electrolytically pretreated urine using state-of-the-art reverse osmosis membrane coupons. These studies and tests will form the basis for a comprehensive document which will define the design requirements for combining electrolytic pretreatment with reverse osmosis in a potable wate relamation unit for a space mission.

A development plan for a combined electrolytic pretreatment/reverse osmosis water system is shown in Figure 1; it describes the manner in which the work outlined in the following section (the dashed box) integrates with past, present, and planned electrolytic pretreatment and reverse osmosis programs. Note that the electrolytic pretreatment unit (EPU) which is presently being

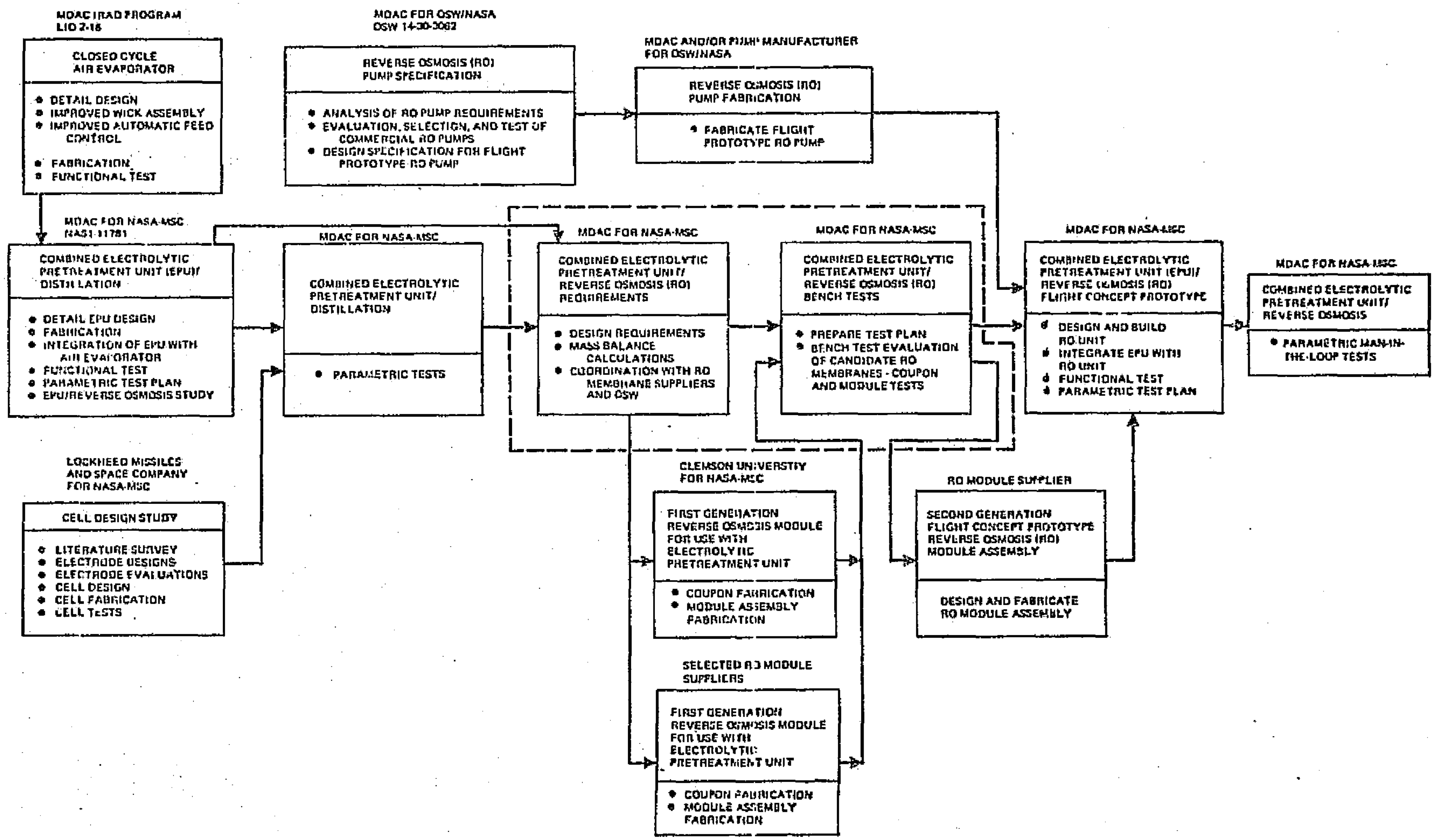

Figure 1. Development Plan for Electrolytic Pretreatment/Reverse Osmosis of Urine

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developed under Contract No. NAS1-11781 and the reverse osmosis pump test stand used in Contract No. OSW 14-30-3062 will both be available for use in the proposed program. The use of these items as GFE should result in significant cost savings to the Government.

The first step in the proposed program will be a series of tradeoff comparisons to assess the optimum electrolytic pretreatment/reverse osmosis configuration for a potable water reclamation system. This study will also deterine whether a final phase-change unit is required with an EPU/reverse osmosis potable water recovery system, and if so, the best placement of the phase-change unit in the flow loop will be identified. The comparison will take into consideration the total water management system, and the required system capacity of each component in the flow loop as a function of reverse osmosis recovery fraction will be determined. Reverse osmosis recovery fractions resulting in minimum sizes and weights for total systems will be identified, and the impact of mission length and resupply period will be evaluated. Preliminary investigations have determined that several configurations are possible for EPU/reverse osmosis spacecraft water reclamation systems. The most promising of these include:

A. Completely separate potable and wash water systems. The potable water system would be composed of a urine electrolytic pretreatment unit followed by a reverse osmosis unit. A phase-change unit would be used, if required, for processing reverse osmosis brine. A schematic of this configuration is shown in Figure 2.

B. An integrated wash and potable water system (see Figure 3) using two reverse osmosis units. The wash water reverse osmosis brine could be input to the potable loop either after (Figure 3A) or before (Figure 3B) electrolytic pretreatment. A phase-change unit would be used, if required, for final processing of the brine.

C. An integrated wash and potable water recovery system using a single reverse osmosis unit. This configuration is shown in Figure 4.

The launch weight and total relative cost of the most favorable configurations identified in the studies will be compared with similar values for other leading candidate potable and wash water recovery systems, including vapor compression, vacuum distillation-vapor filtration, air evaporation, and multifiltration.

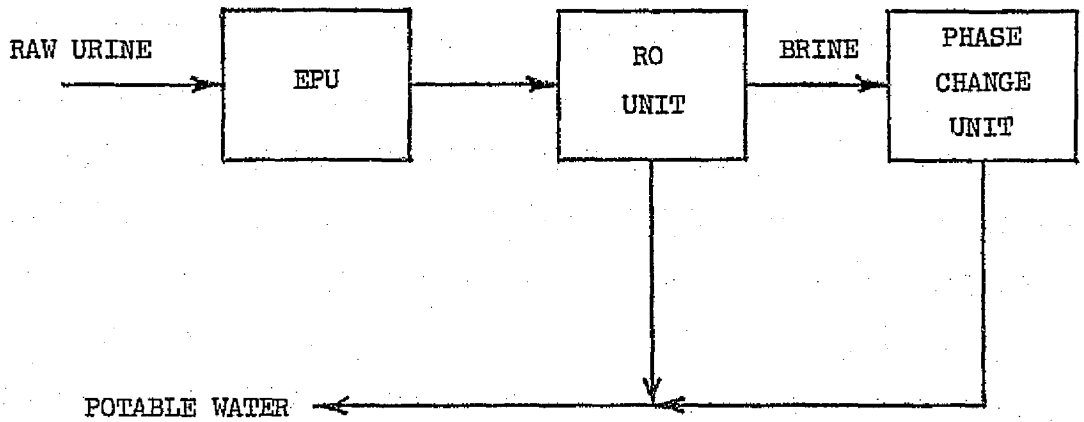


Figure 2. Schematic of Reverse Osmosis (RO)/Electrolytic Pretreatment Unit for Potable Water Recovery System

The method of computation and display format of the results of these comparisons will be similar to those used in Reference 2.

The most favorable system configurations identified will be the basis for additional analyses. Based on the known solutes in pretreated urine and on projected reverse osmosis performance data, a study will be made of required reverse osmosis membrane sizes and of feed, product, and brine compositions and concentrations. The study will cover the expected range of variation in performance and sizing factors projected for space mission use, including solute rejection factors, water recovery fractions, flow rates, pressures, concentration polarizations, and diffusivities. The study will use computer-aided analyses similar to those performed for reverse osmosis wash water systems under Contract No. OSW 14-30-3062 (Reference 2).

The results of the system configuration study and the mass balance and membrane sizing analyses will be used to prepare a preliminary system schematic of the most favorable EPU/reverse osmosis configuration. Flow

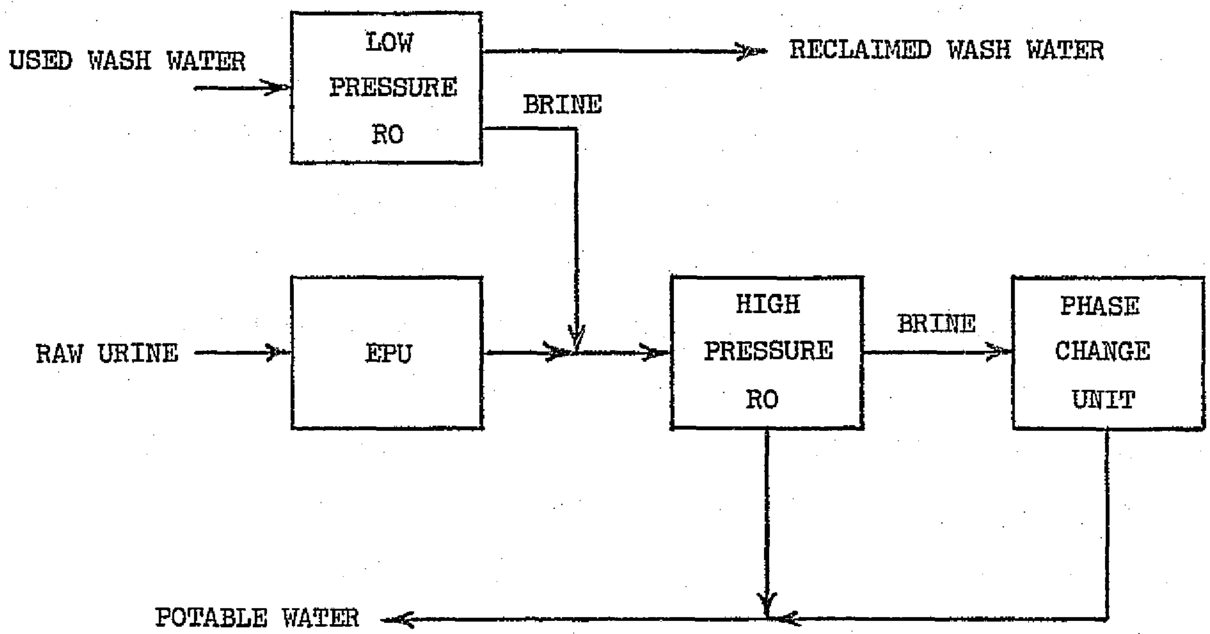


FIGURE 3A WASH WATER INPUT AFTER EPU

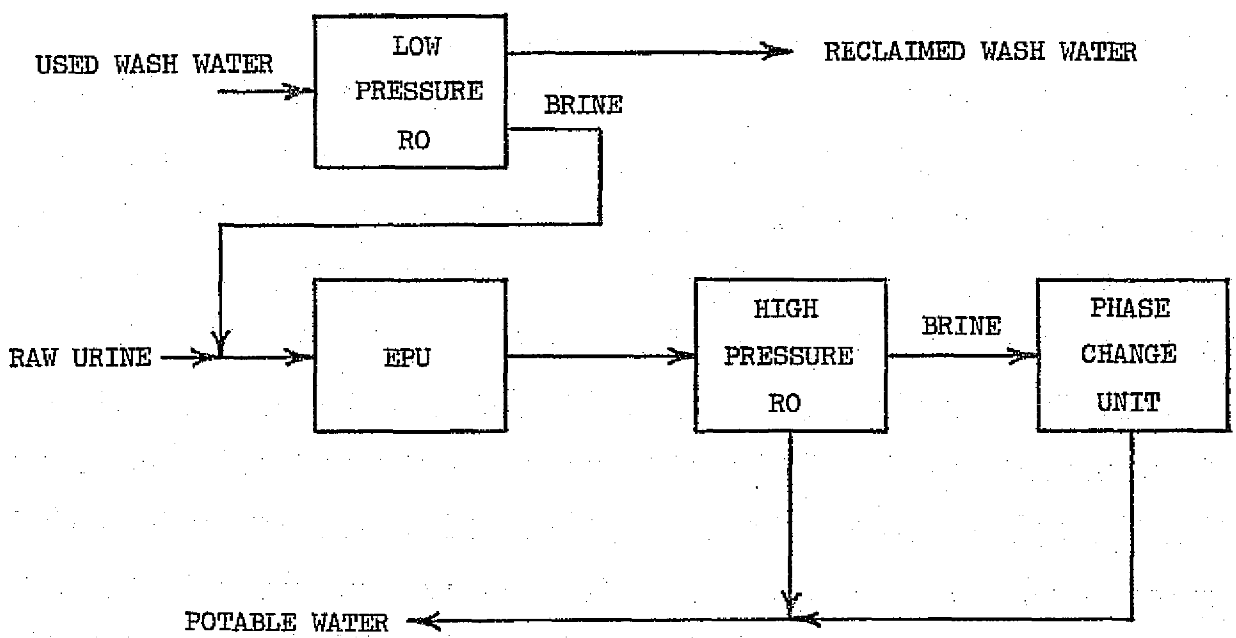


FIGURE 3B WASH WATER INPUT BEFORE EPU

Figure 3. Schematic of Dual Reverse Osmosis (RO) Integrated Potable and Wash Water Recovery System

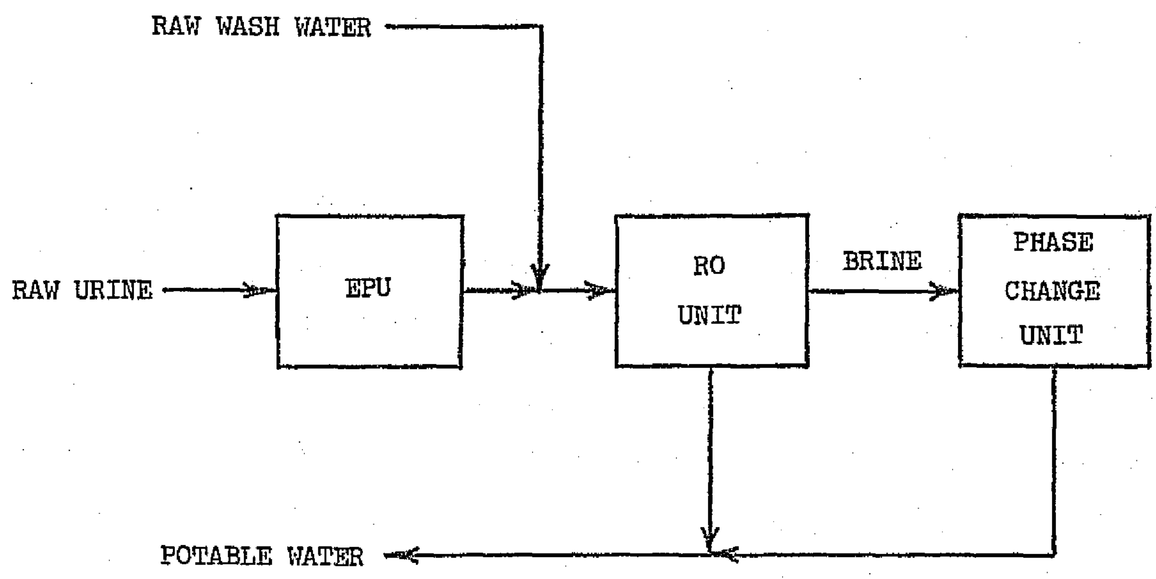


Figure 4. Schematic of Single Reverse Osmosis (RO) Integrated Potable and Wash Water Recovery System

rates, capacities, temperatures, pressures, and other operating characteristics will be defined, and a test procedure will be formulated to evaluate reverse osmosis membrane coupons under these conditions. The test procedure will be structured to use the reverse osmosis pump test stand and the GFE electrolytic pretreatment unit fabricated under other programs with minimum modifications. A test stand and data system will be designed and fabricated to perform the tests specified in the test procedure document. The design will permit unattended operation to the greatest extent possible, and will include automatic safe control and automatic detection and isolation of potentially hazardous or damaging failures.

Based on a study of current reports and suggestions from the contracting agency, MDAC will contact membrane manufacturers on contract award. The manufacturers will be asked to provide typical performance data, conditions of recommended operation, and coupons of each of their types of membrane thought best suited for use with electrolytically pretreated urine. Provisions will be made for use of at least four of these membrane coupons in a series of tests to determine the ability of reverse osmosis membranes to reclaim

potable water from human urine. Such factors as flow rates, membrane degradation, rejection factors for the primary feed solutes, membrane fouling, and pH effects will be evaluated. Table 1 presents a preliminary list of test parameters to be monitored: a finalized measurement list will be compiled in the test procedure document.

Based on the results of the tradeoff, design, and mass balance studies and on results of the coupon tests, a final design requirements document will be prepared which will define the required features of a six-man-capacity, flight-concept, prototype electrolytic pretreatment/reverse osmosis potable water reclamation system. A schematic will be prepared of the integrated EPU/ reverse osmosis system design with system characteristics specified, including such factors as flow rates, operating pressures, interface requirements, acoustic considerations, materials of construction, electromagnetic interference requirements, and output water quality standards. A system control logic table will also be prepared for the design, and major control logic requirements will be identified.

At the conclusion of the contract, a final report will be submitted, providing an historical narrative of all work accomplished under the contract. Graphs, photographs, tables, and other information will be used to describe the work in the most accurate and concise manner possible. Drawings will be included in reduced size, wherever appropriate. The final report will be published after a prior review copy has been approved by the contracting agency. Following approval, MDAC will print and distribute 50 copies of the final report in accordance with a distribution list to be supplied by the contracting agency.

Section 3
STATEMENT OF WORK

MDAC will provide all personnel, materials, services, equipment, and facilities at Huntington Beach, California, which are required to conduct a nine-month program to define requirements for the combination of an electrolytic pretreatment unit with a reverse osmosis water reclamation unit and to conduct tests to characterize the performance of state-of-the-art reverse osmosis membrane coupons to reclaim water from electrolytically pretreated urine.

This program will be accomplished in six major tasks, which are described in the following paragraphs. The tasks correspond to the tasks time-phased on the program schedule in the following section.

3.1 TASK 1 — TRADEOFF AND DESIGN STUDIES AND TEST PROCEDURE DEFINITION

Task 1.1—Tradeoff Study

A study will be made to assess the most favorable electrolytic pretreatment/reverse osmosis configuration for spacecraft potable water reclamation. The study will take into consideration the 'otal water management system (both potable and wash water) and will determine system capacities of each unit in the water loop as a function of reverse osmosis recovery fraction. The fraction resulting in the minimum size and weight for the total system will be identified, and the capacity and placement of a phase-change process, if required, will be defined.

The study will determine the projected launch and resupply weights of the most promising electrolytic pretreatment/reverse osmosis system configurations. Launch and resupply weights and total relative cost figures will be computed for one and 10-year missions and 30, 60, and 360-day resupply periods. The weight and cost values obtained will be compared with similar

values for other leading candidate potable water recovery systems including vapor compression, vacuum distillation-vapor filtration, and air evaporation. Results will be presented in a format similar to that used in Reference 2.

Task 1.2—Mass Balance and Parametric Study

A study will be made of the reverse osmosis feed, product, and brine compositions and concentrations. The study will result in module sizing maps and mass balance data which will cover the expected range of variation in performance and sizing parameters projected for space mission use, including solute rejection factors, water recovery fractions, flow rates, pressures, concentration polarizations, and diffusivities. Most promising EPU/reverse osmosis configurations investigated in Task 1.1 will be included in the mass balance and parametric study.

Task 1.3—Test Procedure Definition

The results of Tasks 1.1 and 1.2 will be used to prepare a preliminary system schematic of a combined EPU/reverse osmosis potable water reclamation system. Flow rates, capacities, temperatures, pressures, and operating characteristics of the system will be defined in sufficient detail to allow formulation of a test procedure to evaluate reverse osmosis membrane coupons under conditions closely resembling those of actual space operation in a laboratory breadboard test unit. The test procedure will be constructed to use the reverse osmosis pump test stand fabricated under Contract No. OSW 14-30-3062 and the EPU fabricated under Contract No. NAS1-11781 with a minimum of modification.

The test procedure document will define in depth the methods, procedures, analyses, measurements, and data recording frequencies required to conduct the tests described in Section 3.4. The test procedure document will incorporate adequate safe control functions to ensure the safety of personnel and equipment during all phases of test operation.

3.2 TASK 2—REVERSE OSMOSIS COUPON TEST SETUP DESIGN

Using the preliminary system schematic prepared in Task 1.3, the design of the membrane coupon test stand will be prepared. The design will be based on the reverse osmosis pump test stand constructed in the performance of

Contract No. OSW 14-30-3062 and will utilize all components of this test stand without modifications, wherever possible. The GFE high-pressure pumps currently being tested for Contract No. OSW 14-30-3062 will be used to pressurize the test coupon feed. Should any of these pumps be unsuitable, replacement pumps with proven performance characteristics will be procured. The design will permit unattended operation to the greatest extent possible and will include automatic safe control and automatic detection and isolation of potentially hazardous or damaging failures.

At ATP, MDAC will conduct a study of current literature. Based on this study and the suggestions of the contracting agency, MDAC will contact manufacturers of reverse osmosis membranes suitable for use with electrolytically pretreated urine. The manufacturers will be asked to provide performance characteristics and coupons of their types of membranes thought best suited for reclamation of potable water from electrolytically pretreated urine. Test provisions will be made for proper use of at least four of the membranes provided. Standard flat-plate shells will be procured during this task to allow testing of the membranes in the test stand.

Working and assembly drawings will be prepared in sufficient detail to permit fabricating and assembling the system. Separate schematic drawings will be prepared to permit construction of additional electrical networks necessary for data monitoring and automatic control of the test operation. Parts required for the fabrication of the test setup will also be identified and purchased during this task.

3.3 TASK 3—REVERSE OSMOSIS COUPON TEST SETUP FABRICATION

Using the working drawings developed during Task 2, the contractor will construct the proposed test setup. Wherever required, component and subassembly tests will be performed to verify operation. Sample test data will be taken immediately after equipment startup to ensure that all data points are recording properly and that all components in the test stand are operating in a normal manner. An informal operations manual will be prepared during this task. It will include the steps and procedures necessary to operate the test setup, including procedures for startup and normal and emergency shutdown. A description of possible operating anomalies will be included, with suggested corrective actions.

3.4 TASK 4—REVERSE OSMOSIS COUPON TEST PROGRAM

Using the test stand constructed in Task 3 and the GFE electrolytic pretreatment unit, a series of tests will be conducted to examine at least four reverse osmosis membrane coupons for water reclamation from human urine. The test conditions will be structured to establish the validity of, the projected reverse osmosis feed, product, and brine stream compositions made in Task 1.3. Such factors as flow rate, membrane life, rejection factors for the primary feed solutes, performance degradation, membrane fouling, and pH effects will be evaluated. Normal operating conditions will be in accordance with the suggestions of the membrane manufacturer for each membrane under test.

During the test of each membrane, data will be taken to record operating conditions and performance. Table 1 presents a preliminary list of test parameters which will be monitored. A final measurement list will be prepared in the performance of Task 1.3.

3.5 TASK 5—DESIGN REQUIREMENTS DOCUMENT PREPARATION

Based on the results obtained from the performance of Tasks 1 and 4, a final design requirements document will be prepared enumerating the required features of a six-man-capacity, flight-concept, prototype electrolytic pretreatment/reverse osmosis potable water reclamation system. A schematic will be prepared of the integrated EPU/reverse osmosis system and system characteristics will be specified, including such factors as flow rates, operating pressures, interface requirements, acoustic considerations, materials of construction, electromagnetic interference requirements, and output water quality standards. A system control logic table will also be prepared for the design, and major control logic requirements will be identified.

3.6 TASK 6—REPORTS

Task 6.1—Monthly Reports

An informal letter-type report will be submitted by the 10th day of the month following ATP and by the 10th day of each month thereafter until the work on the contract is completed. These monthly reports will summarize work done on the contract in the previous month, work to be done in the next reporting

Table 1

PRELIMINARY MEASUREMENT LIST

Item	Recording frequency
Membrane feed pressure	Continuous
Membrane product outlet pressure	Continuous
Membrane brine outlet pressure	Continuous
Membrane differential pressure	Continuous
Feed flow rate	3 times per day
Product flow rate	3 times per day
Brine flow rate	3 times per day
Feed quantity	Once per day
Product quantity	Once per day
Brine quantity	Once per day
Membrane inlet temperature	3 times per day
Membrane outlet temperature	3 times per day
Pump power consumption	Continuous
Heater power consumption	Continuous
Feed, product and brine TDS, mg/liter	As required, but not to exceed once per working day
Feed, product and brine TOC, mg/liter	
Feed, product and brine pH	
Feed, product and brine ammonia, mg/liter	
Feed, product and brine turbidity, Pt-Co units	
Feed, product and brine foaming	
Feed, product and brine odor	
Feed, product and brine urea, mg/liter	
Feed, product and brine lactic acid, mg/liter	
Feed, product and brine NaCl, mg/liter	

period, and the technical and schedule status of the program. Monthly progress reports will not be submitted for the month in which the draft final report is submitted, the month in which the final report is being reviewed by the contracting agency, or the month in which the final report is distributed.

Task 6.2—Final Report

At the conclusion of the contract, a final report will be submitted. It will provide an historical narrative of all work accomplished during the contract. Graphs, photographs, tables, and other information will be used to describe the work in the most accurate and concise manner possible. Drawings will be included in reduced size, wherever appropriate. The final report will be published after a prior review copy has been approved by the contracting agency. Following approval, MDAC will print and distribute 50 copies of the final report in accordance with a distribution list to be supplied by the contracting agency.

3.7 SUBCONTRACTS AND PROCUREMENT

MDAC does not anticipate using any subcontractors on the proposed program. Procurement of materials and services will be made in accordance with established Company-practices.

3.8 GOVERNMENT-FURNISHED EQUIPMENT

The GFE to be used in this program on a no-cost, noninterference basis is identified as follows:

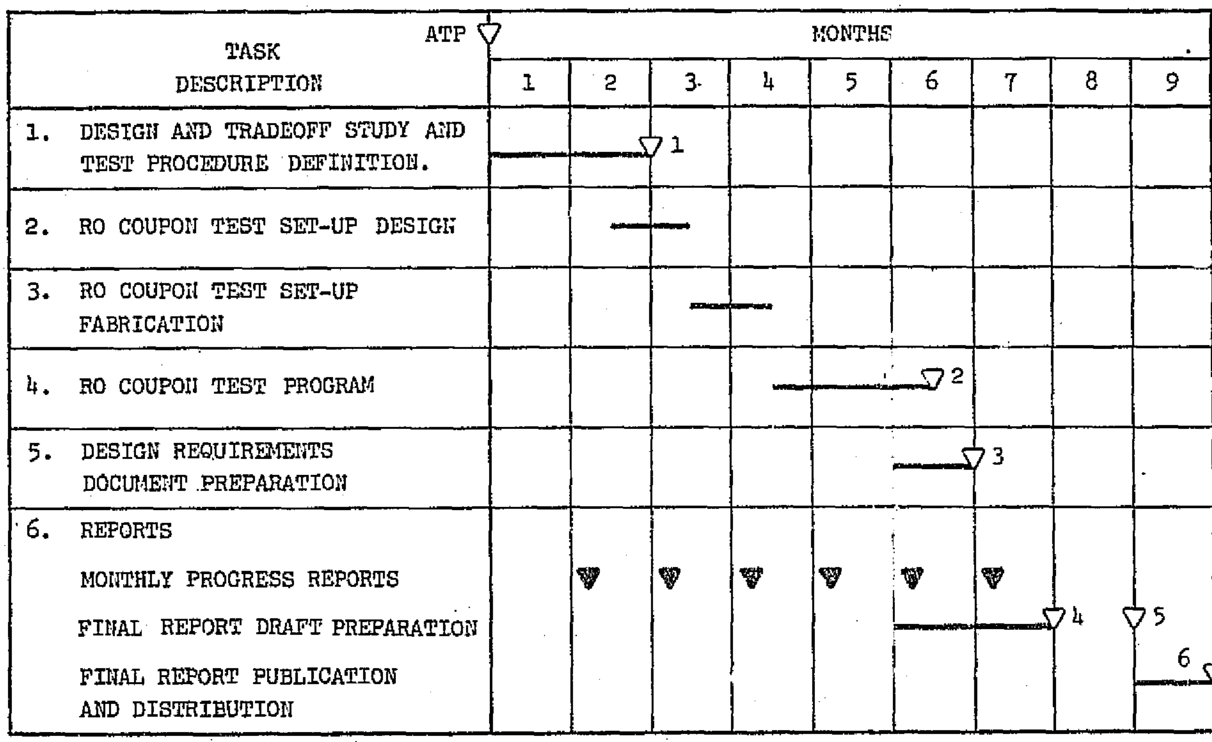
A. One electrolytic pretreatment unit as developed by MDAC for NASA under Contract No. NAS1-11781.

B. Four high-pressure reverse osmosis pumps purchased under Contract No. OSW 14-30-3062.

Both items are presently in-house at MDAC.

Section 4
SCHEDULE

The proposed program schedule is shown in Figure 5. Some of the key goals of the proposed program have been designated as milestones and are so indicated on the schedule. The tasks time-phased on the schedule correspond to those outlined in Section 3.



MILESTONES

1 DESIGN AND TRADEOFF STUDY AND TEST PROCEDURE DEFINITION COMPLETE

2 RO COUPON TEST PROGRAM COMPLETE

3 DESIGN REQUIREMENTS DEFINITION COMPLETE

4 FINAL REPORT DRAFT SUBMITTED FOR REVIEW

5 CUSTOMER REVIEW OF FINAL REPORT DRAFT COMPLETE

6 FINAL REPORT PUBLICATION AND DISTRIBUTION COMPLETE

Figure 5. Program Schedule

Section 5

REFERENCES

1. L. M. Kindley, H. E. Podall, and J. N. Pecoraro. Application of Reverse Osmosis to Wash Water Recovery For Manned Space Flights, ASME Paper 71-Av-1, July 1971.

2. Definition of Reverse Osmosis Requirements for Spacecraft Wash Water Recycling, Contract No. OSW 14-30-3062 Final Report, MDC G3780, Nov. 1972.

3. D. F. Putnam and R. L. Vaughn. Water Reclamation from Urine by Electrolysis-Electrodialysis, ASME Paper 71-Av-11, July 1971.

4. Combination of an Electrolytic Pretreatment Unit with Secondary Water Reclamation Processes, Preliminary Design Report, MDC G3851, Sept. 1972.